

**DEVELOPING FREEWAY MERGING CALIBRATION
TECHNIQUES FOR ANALYSIS OF RAMP METERING IN
GEORGIA THROUGH VISSIM SIMULATION**

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The Academic Faculty

by

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**DEVELOPING FREEWAY MERGING CALIBRATION
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GEORGIA THROUGH VISSIM SIMULATION**

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LIST OF ABBREVIATIONS

Accel	Acceleration Lane Data Collection Point
AdvMerge	Advanced Merging
CL.Enter	Center Lane Entrance Data Collection Point
CL.Exit	Center Lane Exit Data Collection Point
CL.Merge	Center Lane Merging Area Data Collection Point
COM	Component Object Model
Coop. Braking	Cooperative Braking
DOT	Department of Transportation
HCS	Highway Capacity Software
HOV	High-Occupancy Vehicle
IDS	Incremental Desired Speed
ITS	Intelligent Transportation System
ft	Feet
ft/sec ²	Feet per second squared
GDOT	Georgia Department of Transportation
LL.Enter	Left Lane Entrance Data Collection Point
LL.Exit	Left Lane Exit Data Collection Point
LL.Merge	Left Lane Merging Area Data Collection Point
Mph	Miles per Hour
On.Ramp	On-Ramp Data Collection Point
Ramp.Meter	Ramp Meter Data Collection Point
RL.Enter	Right Lane Entrance Data Collection Point
RL.Exit	Right Lane Exit Data Collection Point

RL.Merge	Right Lane Merging Area Data Collection Point
SWARM	System Wide Adaptive Ramp Metering
TOD	Time of Day
Vehs	Vehicles
Veh/ln	Vehicles per Lane
Veh/ln/hr	Vehicles per Lane per Hour
Vol	Volume
VDS	Video Detection System

SUMMARY

Freeway merging VISSIM calibration techniques were developed for the analysis of ramp metering in Georgia. An analysis of VISSIM's advanced merging and cooperative lane change settings was undertaken to determine their effects on merging behavior. Another analysis was performed to determine the effects of the safety reduction factor and the maximum deceleration for cooperative braking parameter on the simulated merging behavior. Results indicated that having both the advanced merging and cooperative lane change setting active produced the best results and that the safety reduction factor had more influence on the merging behavior than the maximum deceleration for cooperative braking parameter. Results also indicated that the on-ramp experienced unrealistic congestion when on-ramp traffic was unable to immediately find an acceptable gap when entering the acceleration lane. These vehicles would form a queue at the end of the acceleration lane and then be unable to merge into the freeway lane due to the speed differential between the freeway and the queued ramp traffic. An Incremental Desired Speed algorithm was developed to maintain an acceptable speed differential between the merging traffic and the freeway traffic. The Incremental Desired Speed algorithm resulted in a smoother merging behavior. Lastly, a ramp meter was introduced and an increase in both the freeway throughput and overall speeds was found. Implications of these findings on the future research is discussed.

CHAPTER 1

INTRODUCTION

The continued growth of traffic congestion on Georgia's transportation system has greatly impacted the ability to move people and goods from one location to another. Surveys provided by Atlanta's own metropolitan planning organization, the Atlanta Regional Commission, have shown that since 2013, citizens are becoming more concerned with the transportation situation of the metro Atlanta region [1]. The latest survey in fact showing that over a quarter of survey takers, at 27%, polled transportation as the biggest concern followed by crime (17%), the economy (15%) and public education (14%) [1].

Compounding the transportation issue, Georgia's state and local governments have strict or dwindling budgets that will not allow the construction of new larger transportation facilities. Furthermore, while elected officials agree that the Atlanta region's transportation network needs help, "how they will fix it and who will benefit most is a point of contention [2]." Even if the funds were available, the induced traffic demand brought on by adding new lanes or facilities could leave Atlanta's transportation system in the same state of traffic congestion. Taking in consideration the budget issues and the effects of induced traffic demand, a current option for Atlanta is to find ways to work with what is already in place. One way to accomplish this is to more effectively use the ramp meters that are already in place on the freeway on-ramps to control the rate of vehicles entering the freeway system. This thesis supports that goal by developing calibration techniques for a freeway merging modeling for the analysis of ramp metering in Georgia.

1.1 Background

By taking the system of ramp meters already in place in Georgia and implementing a new system wide interconnected ramp metering control strategy, it could be possible to control the total traffic volumes on the freeway system. For a system wide interconnected ramp metering system to work in Georgia, a system or algorithm needs to be in place that can analyze data being collected from the entire freeway system and adjust every ramp meter's signal timing to optimize the total number of cars entering the freeway.

To test and develop an effective system wide interconnected ramp metering control strategy, a suitable traffic simulation modeling software must be chosen. The chosen model needed to be customizable in that various ramp geometries may be analyzed, multiple mainline and ramp volumes may be tested, and that a ramp meter may be implemented on the on-ramps. Keeping these criteria in mind, three available modeling options were considered for this project: the Highway Capacity Manual (HCM) implemented using the Highway Capacity Software (HCS), PTV-VISSIM 5.4 (a microscopic simulation tool), or to create a custom model.

Given the time constraints and complexity of the task, creating a model was not considered viable. HCS was the preferred model to analyze ramp freeway junctions as it requires a much lower implementation effort than VISSIM. HCS provides capacity estimates, considers the impacts of adjacent on- and off-ramps, provides a single deterministic estimate of traffic density, and can be coded to produce multiple result files for varying traffic conditions. VISSIM would then only be used to verify the results produced by the HCS software and to work out any calibration to the HCS results if needed. However, it was determined that HCS software does not adequately model a ramp meter and cannot model all of the ramp geometries existing within the Georgia freeway network. Certain geometry features, such as an on-ramp becoming an additional lane to the freeway, which is common in Georgia, cannot be reflected within HCS. The

HCS only allows for a maximum acceleration lane length of 1,500ft [3], thus forcing cars to merge which wouldn't otherwise need to in the field.

Based on these issues it was determined to move forward with the PTV-VISSIM 5.4. Through PTV-VISSIM, any ramp geometry could be created and analyzed, in addition it includes the ability to implement a ramp metering system. However, when a PTV-VISSIM model of an on-ramp was created, the calibration of the freeway merging behavior became a complex problem. This led to the focus of this thesis to develop freeway merging calibration techniques for the analysis of ramp metering in Georgia using PTV-VISSIM simulation.

1.2 Project Goals

The goal of this project is to create a basic understanding of how changes to the VISSIM vehicle driver behavior parameters will change the outcome of a freeway merging simulation. This will be accomplished by completing a series of analyzes on available features and settings that affect the merging behavior within the VISSIM simulation. The first analysis presented explores the effects that both the Advanced Merging and Cooperative Lane Change features have on the speed-flow relationship in merging locations, the number of recorded diffusions, and the remaining vehicles that could not enter the system. The second analysis considers the effects that both the Safety Distance Reduction Factor (also called the safety factor) and the Maximum Deceleration for Cooperative Braking parameters (cooperative braking) on the vehicle merging behavior. Both the safety factor and cooperative braking parameter are user defined values which allow for a range of value combinations.

The third analysis introduces a developed Incremental Desired Speed (IDS) algorithm COM (Component Object Model) code. This analysis will consider two parameters within the IDS code that allow for varying degrees of adjustment to its

function. The final part of the project will compare a non-ramp metered and a ramp metered case.

1.3 Thesis Organization

This thesis is organized in the following manner. Chapter 2 is a literature review that covers the background of ramp metering in Georgia, the basic types of ramp metering control, freeway merging behavior, and finally merging behavior within a VISSIM simulation. Chapter 3 describes the development of the VISSIM model used for this project and describes the methodology of the analysis performed using the model. Chapter 4 presents the key results from each analysis. Chapter 5 is the conclusion to this thesis discussing the results from each analysis. Chapter 5 concludes with an explanation of the next steps.

CHAPTER 2

LITERATURE REVIEW

This literature review reports the current and historical use of ramp metering in Georgia as well as on freeway merging behavior research related to VISSIM. This review will discuss the different types of ramp metering control in practice. Furthermore, an idea of where to begin with calibrating the VISSIM merging behavior to reflect real world observations can be obtained through other research that studied freeway merging behavior.

2.1 Background of Ramp Metering in Georgia

Ramp metering is an effective, viable, and practical strategy to manage freeway traffic [4]. Georgia has had ramp meters in Atlanta as early as the 1960's, but their existence was short lived once the freeways were widened and the ramps improved [5]. It was not until the 1996 Olympics in Atlanta that Georgia began to consider implementing ramp meters as a viable traffic control device. Since 1996 ramp meters in Georgia have come about through four main generations [6]. The first generation, called the Olympic Era, was implemented in 1996 in preparation for the Olympics and consisted of four sites on I-75 Northbound but only for the Olympic venues north of Atlanta [5, 6]. These ramp meters used inductive loops on the on-ramps and ran using "TOD operations with no freeway detection [6]." These ramp meters were also connected to the Georgia Department of Transportation (GDOT) NaviGator Intelligent Transportation System (ITS) which consists of "of surveillance cameras, vehicle detection system cameras, Changeable Message Signs , and ramp meters [7]."

The second generation of ramp metering in Georgia occurred during 2005 as part of a study done by GDOT to test the effectiveness of ramp meters. The study consisted of

four locations on the I-75/I-85 Downtown Connector for the Southbound direction only and introduced the use of video detection and the metering of multilane on-ramps [6]. These ramp meters were also connected to the NaviGator ITS system and ran using a TOD schedule but also benefitted from the use of an “early-on” feature that would turn the ramp meter on sooner if freeway volumes were high. The third generation of ramp metering was on State Road 400 in 2006 and consisted of eight sites. It is important to note that at the time these ramp meters were not operational nor were they connected to the NaviGator ITS system [6].

The fourth generation of Georgia ramp meters came in 2006 and was a part of Governor Sonny Perdue’s 2004 Fast Forward Congestion Relief Program [5-7]. This was an ambitious project for GDOT as it included installing 165 new ramp meters along all the major freeways around Atlanta by 2012 [5]. Beyond the number of new ramp meters to be installed, this was Georgia’s first attempt at implementing a system wide ramp metering algorithm to control the ramp metering signal timing. Using a modified version of the System Wide Adaptive Ramp Metering (SWARM) algorithm, originally developed by the National Engineering Technology Corporation under a contract with the California Department of Transportation, SWARM can control groups of ramps based on downstream freeway congestion [6, 8]. Table 1 shows the improvements of travel times for a selection of corridors where ramp meters were installed. What can be seen from Table 1, is that for the selected corridors there were considerable travel time savings once the ramp meters were activated.

Table 1: A Selection of Corridor Travel Time Improvements [5]

Corridor	Before Travel Time (mins)	After Travel Time (mins)	Savings
I-75/85 NB Langford to I-20	11	7.5	32%
I-285 WB GA 400 to I-75	16	13.5	16%
I-75 NB I-285 to Wade Green Rd	26	20	23%
I-75 SB Wade Grn to I-285	25	19	24%
I-285 NB from US 78 to I-85	10	7.5	25%
I-85 NB from 285 to Pleasant Hill	24	15	38%

2.2 Ramp Metering Control

There are two overall categories of ramp metering control algorithms used to operate ramp meters within a freeway system. The first category is called Local Control and the second category is called System Wide control [9, 10]. These two categories for ramp metering control will be discussed in the next two sections.

2.2.1 Local Control

Local control ramp metering algorithms, also known as isolated ramp metering algorithms, determine metering rates based on the local traffic conditions present at an individual ramp and are only based on conditions observed upstream or downstream of the ramp [9, 10]. These types of strategies are relatively simple and do not typically require a large capital investment or communication system compared to system wide algorithms.

There are two main philosophies within local control algorithms for determining metering rates: a Feed-forward philosophy and a Feedback philosophy [11]. A feed-forward philosophy algorithm uses reactive traffic response techniques to determine

metering rates. For these types of algorithms, metering rates only are applied once traffic congestion on the mainline has occurred which is considered to be a main drawback for this approach [11]. A feedback philosophy algorithm is opposite of a feed-forward algorithm and tries to avoid congestion before it occurs. Using measurements of the downstream occupancy, a feedback algorithm will try to maintain a desired level of occupancy. The ALINEA Algorithm, originally developed by the Technical University of Munich, is a very common local control metering algorithm that uses a feedback philosophy to determine metering rates [12, 13].

2.2.2 System Wide Control

System wide control algorithms are implemented when ramp metering is needed to reduce congestion for a larger transportation system and not for a single localized area. The advantage of using a system wide algorithm over local metering algorithms is their ability to be able to collectively gather traffic data from an entire region and control a network of ramp meters. These algorithms use data collected from the freeway system and analyze it to determine metering rates for the various meters to reduce congestion.

There are three general strategies types that system wide algorithms can use to determine metering rates. These are, cooperative strategies, competitive strategies, and finally integral ramp metering strategies [14]. Cooperative strategies first calculate a metering rate based on the local ramp conditions and then adjust that rate based on the conditions of the freeway system. Competitive strategies will calculate two rates; one metering rate based on the local conditions and another on the system conditions. The more restrictive of the two metering rates is then implemented. Integral strategies use both the local and system conditions to determine a metering rates. A few examples of common system wide algorithms that are being used include the SWARM algorithm, the Seattle Bottleneck algorithm, the Minnesota Zone algorithm, and the Washington State DOT FUZZY Logic system [8-10, 14, 15].

2.3 Modeling Freeway Merging Behavior Within VISSIM

“Freeway entrance ramp accelerations and merging processes are complex and have significant impacts upon the freeway traffic operations [16].” The number of variables that determine how or when a driver decides to commit to merging or making a lane change makes this behavior difficult to capture within a traffic simulation model [17]. In using the VISSIM 5.40 simulation traffic tool, which is a discrete, stochastic, time step based microscopic model that was developed by the PTV Group of Germany, calibrating the car following and lane changing parameters correctly is an essential part of accurate simulations [18, 19].

2.3.1 Wiedemann 99 Car Following Model Parameters

VISSIM’s car following model is “based on the work of Wiedemann and combines a perceptual model of the driver with a vehicle model [18, 20].” Within Wiedemann’s 99 Car Following Model, the model used for freeway simulation, there are four distinct driver modes that are defined that a driver may participate in: free driving, approaching, following, and braking [18, 20]. A driver under the free driving mode will feel no influence from any of the other vehicles around them and will continue to pursue their own desired speed. A driver in the approaching mode will be adjusting their speed according to the preceding vehicles by applying a deceleration. A driver in the following mode is simply maintaining an adequate safety distance behind a preceding car without any further acceleration or deceleration. Lastly, a driver in the braking mode will apply a medium to high deceleration in preparation of stopping or if the desired safety distance is no longer achievable. For each of these modes a driver’s acceleration and deceleration characteristic differs and based on their following distances and desired speeds a driver’s mode can change based on the roadway conditions [18, 20]. All of which changes the capabilities of that driver for merging and making a lane change [18].

Wiedemann's 99 car following model does consist of a set of parameters that can be "adjusted to better match real-world conditions, especially when trying to match flow rates and achieve particular capacities [21]." These parameters, listed as CC0-CC9, control various aspects of the car following behavior. Table 2 from Oregon DOT's Protocol for VISSIM Simulation handbook lists these parameters along with a description of the parameters function, the default value of parameters as well as the suggested ranges that the Oregon DOT would allow in their own VISSIM simulations.

Table 2: Suggested Oregon DOT Wiedemann 99 Car Following Parameters [21]

		Default	Unit	Suggested Range	
				Basic Segment	Merging / Weaving
CC0	Standstill Distance	4.92	ft	4.5 - 5.5	> 4.92
CC1	Headway Time	0.9	s	0.85 - 1.05	0.90 1.50
CC2	'Following' Variation	13.12	ft	6.56 - 22.97	13.12 - 39.37
CC3	Threshold for Entering 'Following'	-8		use default	
CC4	Negative 'Following' Threshold	-0.35		use default	
CC5	Positive 'Following' Threshold	0.35		use default	
CC6	Speed Dependency of Oscillation	11.44		use default	
CC7	Oscillation Acceleration	0.82	ft/s ²	use default	
CC8	Standstill Acceleration	11.48	ft/s ²	use default	
CC9	Acceleration at 50 mph	4.92	ft/s ²	use default	

According to the Oregon DOT's VISSIM Protocol, "CC0 (Standstill Distance), CC1 (Headway Time), and CC2 (Following Variation) have the greatest influence on car following behavior in VISSIM." That is because those three parameters are the key parameters used in determining the desired safety distance. For VISSIM, the standstill distance (CC0) is defined as the desired rear-bumper to front-bumper distance between stopped cars. This controls how closely traffic can pack in together which can change

some performance measures, such as queue length and traffic density. Figure 1 shows what this distance looks like.



Figure 1: Standstill Distance Parameter (CC0) [21]

To determine the desired safety distance, VISSIM takes the standstill distance (CC0) and adds the headway time parameter (CC1) multiplied by the speed the vehicle is traveling. The equation for this calculation is described below as:

$$\text{Desired Safety Distance} = CC0 + (CC1 \times \text{speed})$$

Figure 2 shows the visualization of the desired safety distance.

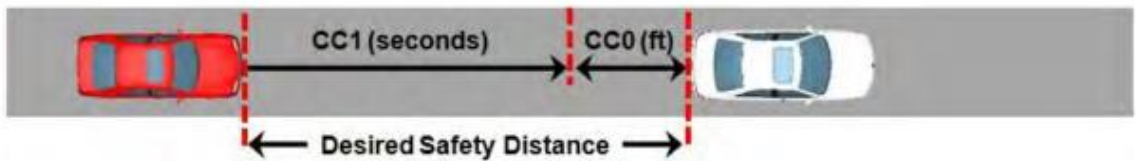


Figure 2: Desired Safety Distance Using CC0 and CC1 Parameters [21]

Lastly, VISSIM incorporates the CC2 following variation parameter by adding that length value to the calculated desired safety distance and “it defines how much more distance than the desired safety distance before the driver intentionally moves closer to the lead vehicle [21].” At any point while a driver is following another vehicle it will maintain a distance between the desired safety distance (the minimum) and the desired safety distance plus the following variation (the maximum). By varying the CC0-CC2 parameters, the available gap sizes for vehicle to merge into can be greatly affected.

Figure 3 shows the final visualization of these three parameters on the distances creating a gap between two vehicles.

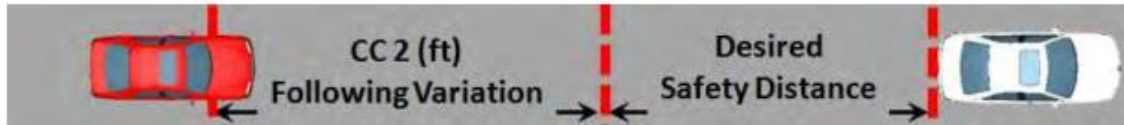


Figure 3: Desired Safety Distance Plus the CC2 Following Variation [21]

While the Oregon DOT only suggests to adjust the CC0-CC2 parameters, there are other studies that have done more by adjusting some of the other parameters. In a study done by Gomes et al., which included simulating a 15-mile section of I-210 West in Pasadena, California in VISSIM, they adjusted the CC4 and CC5 values and stated that these parameters at smaller absolute values results in driver behavior being more sensitive to changes in the speed of the preceding vehicle. It should be noted that when adjusting the CC4/CC5 parameters it is recommended the two parameters have opposite signs and equal absolute values [22]. Another study stated that for their research it was required for them to adjust the CC8 and CC9 parameters as well [19].

2.3.2 Lane Changing Parameters

There are two types of lane changes defined within VISSIM [22]. The first type of lane change is called the necessary lane change. A necessary lane change is required when a vehicle must reach the next connector of a route within the VISSIM model. Examples of when a necessary lane change is required include lane drops, freeway on-ramps, and freeway off ramps. The second type of lane change within VISSIM is called the free lane change. A vehicle will perform a free lane change because there is either more room or higher speeds in the adjacent lane. For both of these lane change types, it is first required that the driver find a suitable gap within the destination lane [18]. The size

of the gaps available for a driver to merge into were shown to be affected by the Wiedemann 99 Car Following parameters in the last section; however, the “aggressiveness” in which drivers will try to make those gaps is adjusted through a set of lane change parameters [22].

A majority of the lane change parameters available to adjust fall within the driver behavior parameter sets under the Lane Change window. Figure 4 shows a screen capture of this location.

The screenshot shows the 'Driving Behavior Parameter Sets' window. On the left, a list of parameter sets is shown, with '3 Freeway (free lane selection)' selected. The main window displays the 'Lane Change' tab for this set. The 'General behavior' dropdown is set to 'Free Lane Selection'. The 'Necessary lane change (route)' section contains a table with parameters for 'Own' and 'Trailing vehicle'. Below this, several other parameters are listed with input fields. At the bottom, there are checkboxes for 'Cooperative lane change' and 'Advanced merging', and two more parameters: 'Maximum speed difference' and 'Maximum collision time'.

Necessary lane change (route)		Own	Trailing vehicle
Maximum deceleration:		-13.12 ft/s ²	-9.84 ft/s ²
- 1 ft/s ² per distance:	200.00 ft		200.00 ft
Accepted deceleration:		-3.28 ft/s ²	-1.64 ft/s ²

Waiting time before diffusion:	60.00 s
Min. headway (front/rear):	1.64 ft
To slower lane if collision time above:	0.00 s
Safety distance reduction factor:	0.60
Maximum deceleration for cooperative braking:	-9.84 ft/s ²

Overtake reduced speed areas ☐

Advanced merging ☒

☒ Cooperative lane change

Maximum speed difference:	6.71 mph
Maximum collision time:	10.00 s

Figure 4: Lane Change Parameters Window from VISSIM 5.40

Beginning with the necessary lane change section of Figure 4, there is the option to adjust the deceleration values of the lane changer (Own) and the vehicle that the lane changer is moving in front of (Trailing vehicle). The range of the decelerations for these vehicles is bound by the accepted deceleration and the maximum deceleration. The middle parameter is a reduction rate which is used to reduce the maximum deceleration

with increasing distance from the emergency stop position [22]. In other words, a vehicle will use its accepted deceleration value but will continue to have a more aggressive deceleration as the vehicle approaches the last possible position for that vehicle to change lanes.

The next group of parameters consist of a waiting time before diffusion, a minimum headway value, a safety distance reduction factor, the maximum deceleration for cooperative braking, an overtake reduced speed areas feature, an advanced merging feature, and a cooperative lane change feature. The waiting time before diffusion is the given time a vehicle, if unable to move in the VISSIM model when attempting to move, will sit and wait within the simulation before VISSIM simply removes the vehicle from the simulation completely and produces an error file [20, 21]. This value can be reduced from the default 60 seconds to reduce the impacts of a vehicle not moving and causing some form of lane blocking; however, caution should be exercise in the use of this parameter. Within the Oregon DOT VISSIM Protocol, it states that because a diffusion signifies an error, that there could be a coding error and it should be investigated as to why a vehicle is not moving for one minute. This differs from the view of the Gomes et al. study in Pasadena, California on I-210 West who changed the diffusion time from 60 seconds to 1 second. Stating that the reduction in diffusion time minimized the obstruction to the freeway and because a diffusion was a rare event for their simulation there was little impact on their collected travel times [20].

The minimum headway is “the minimum distance to the vehicle in front that must be available for a lane change in a standstill condition [18].” If cars are spaced closer than this value, then stopped cars will not pull out to change into the adjacent lane. The safety distance reduction factor (also referred to as the safety factor) is an important parameter as it is directly related the desired safety distance, which is a part of the car following gap size. Essentially the safety reduction factor is used to temporarily shorten the desired safety distance, which shortens the accepted gap, during a lane change. Once the lane

change is complete the original safety distance is regarded again [22]. For example, a safety reduction factor of 0.6 will reduce the original safety distance by 40%, thus making merging traffic more aggressive since they will accept smaller gap sizes.

The maximum deceleration for cooperative braking is the maximum deceleration a car will undergo to try and allow another car in an adjacent lane needing to make a mandatory lane change to merge into its lane [22]. This parameter is given to achieve a more realistic merging scenario where mainline vehicles are slowing down to allow other vehicle to merge in. The overtake reduced speed area box is left unchecked by default and deals with lane changes within a reduced speed zone. The advanced merging is an option available that when checked will allow “more vehicles to change lanes earlier; thus, the capacity will increase and the probability of standing vehicles waiting for a lane change will be reduced [22].” The cooperative lane change feature further creates a more realistic merging behavior within VISSIM. The basic function of this feature is that if a vehicle “A” sees that another vehicle “B” in an adjacent lane needing to make a mandatory lane change, then vehicle “A” will change lanes in order to create a gap for vehicle “B” [22].

Table 3 is a table created by the Oregon DOT and suggests a range of values for the lane change parameters to be used within their own VISSIM simulations. What can be seen within this table is a list of all the default values for each of the given lane change parameters that appeared in Figure 4. The second item to notice is that some of the suggested range values either don’t change from the default (such as the time before diffusion) and that the given ranges allow for an assortment of different parameter combinations.

Table 3: Oregon DOT Suggested Lane Change Parameters [21]

DEFAULTS				
General Behavior	Free Lane Selection			
Necessary Lane Change (route)	Own	Unit	Trailing Vehicle	Unit
Maximum deceleration:	-13.12	ft/s ²	-9.84	ft/s ²
-1 ft/s ² per distance:	200	ft	200	ft
Accepted deceleration:	-3.28	ft/s ²	-1.64	ft/s ²
Waiting time before diffusion:			60	s
Min. headway (front/rear):			1.64	ft
To slower lane if collision time above:			0	s
Safety distance reduction factor:			0.6	
Maximum deceleration for cooperative braking:			-9.84	ft/s ²
Overtake reduced speed areas:			<input type="checkbox"/> *	
SUGGESTED RANGES				
General Behavior	Free Lane Selection			
Necessary Lane Change (route)	Own	Unit	Trailing Vehicle	Unit
Maximum deceleration:	-15 to -12	ft/s ²	-12 to -8	ft/s ²
-1 ft/s ² per distance:	150 to 250	ft	150 to 250	ft
Accepted deceleration:	-2.5 to -4	ft/s ²	-1.5 to -2.5	ft/s ²
Waiting time before diffusion:			60	s
Min. headway (front/rear):			1.5 to 2	ft
To slower lane if collision time above:			0 to 0.5	s
Safety distance reduction factor:			0.25 to 1.00	
Maximum deceleration for cooperative braking:			-8 to -15	ft/s ²
Overtake reduced speed areas:			<input type="checkbox"/> *	

* Leave box un-checked

Other lane change parameters not found this same location as these other parameters is the emergency stop distance and the lane change distance which can be found in the connector data window. An image of the connector data window is shown in Figure 5.

Connector

No.: 10000 Name:

Behavior Type: 1: Urban (motorized) ▼

Display Type: 1: Road gray ▼

from link: to link:

No.: 1 No.: 2

At: 1290.026 ft At: 5.281 ft

Lane 1 Lane 1

☒ Spline: # Points: 2

Lane Change Display Dyn. Assignment Other

Lane Closure... No Lane Change...

Route

Emergency Stop: 16.4 ft back

Lane change: 656.2 ft back ☐ per lane

Desired Direction

☒ All ☐ Right ☐ Left

OK Cancel

Figure 5: Connector Data Window from VISSIM 5.40

Before changing the emergency stop distance and the lane change distance, it is important to change the connector's behavioral type at the top of the window to Freeway in order for the connector to reflect the correct Wiedemann car following parameters if a freeway is being simulated.

The emergency stop distance is the closet position a vehicle needing to make a lane change will drive up to and stop if they have not made their lane change. By moving this position around, vehicles will stop at different locations, which could be beneficial for some roadway geometry type where completing a lane change is more difficult the closer a vehicle is to its desired route.

The lane change distance, also called the look-back distance in some literature [20], is a user defined distance at which vehicles will begin to attempt making lane changes to reach their desired routes [22]. Once a vehicle reaches that point, all lane changes will take in consideration the desired connector [23]. For simulating a freeway this parameter affects the ease in which traffic can get to an off ramp and exit the freeway. With short lane change distances, cars will wait to the last minute to make the necessary lane changes; thus blocking the through travel lanes on the freeway. There can also be an issue with making the lane change distance too large. This creates an “unrealistic effect of bunching up all of the exiting vehicles in the right-most lane, far upstream of their intended off ramp [20].” Furthermore, due to the variation that may be seen with different lane change distances, it may become necessary to adjust each ramp’s lane change distance individually. A simple first step is to set the lane change distance at the location of the first overhead highway sign [22].

Another use for the lane change distance to be aware of is when modeling merge areas near on-ramps, the connector at the end of the merge link should have a lane change distance longer than the entire merge area. Which eliminates cars in the mainline from merging into the acceleration lane to pass vehicles before getting back onto the mainline.

CHAPTER 3

VISSIM MODEL DEVELOPMENT

Chapter 3 presents the development of the VISSIM model used to simulate the merging behavior of an on-ramp. The geometry and basic set up of the model with the required inputs will be discussed, as well as the structure of the COM code used to run the model. Chapter 3 then will go through the methodology of each driver behavior analysis performed and introduce the Incremental Desired Speed (IDS) Algorithm. Lastly, Chapter 3 will conclude with the methodology for implementing a ramp meter on the on-ramp.

3.1 Network Coding

This section will present the structure and layout of the VISSIM model as well as discuss the COM simulation code used to run the model.

3.1.1 VISSIM Model Structure and Layout

The created VISSIM model consists of a three lane freeway with a single lane on-ramp that has an acceleration lane of 1,500ft. In total, the model contains three links and four connectors. There is a link for the entering and exiting mainline freeway traffic, a link for the on-ramp, and a link for the effective merging area which includes the three mainline through lanes and the on-ramp acceleration lane. The connectors of the model connect the entering link and on-ramp link to the effective merging area link, which then ends with one connector connecting to the exiting mainline link. This process for setting up the link and connectors follows the process described within the Oregon DOT Protocol for VISSIM Simulation. A fixed timed signal was also placed upstream on the on-ramp to produce the platooning effect of cars entering the freeway system.

Figure 6 displays the model as it appears in VISSIM and Figure 7 displays the VISSIM model with the links colored blue and the connectors colored pink. Also seen within Figure 6 is the location of the data collection points used to collect both the volume and speed data for each travel lane.

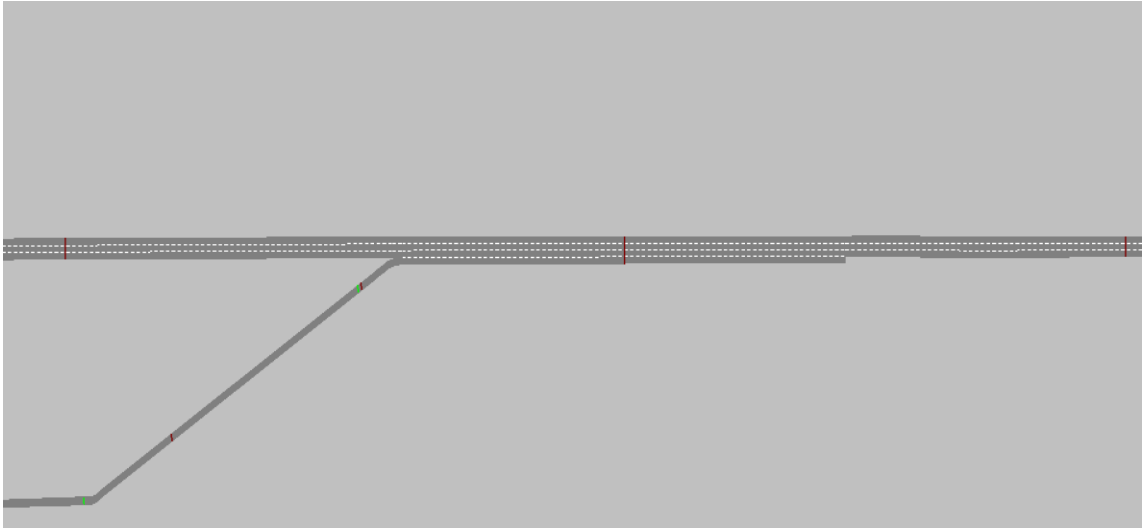


Figure 6: Designed VISSIM Model

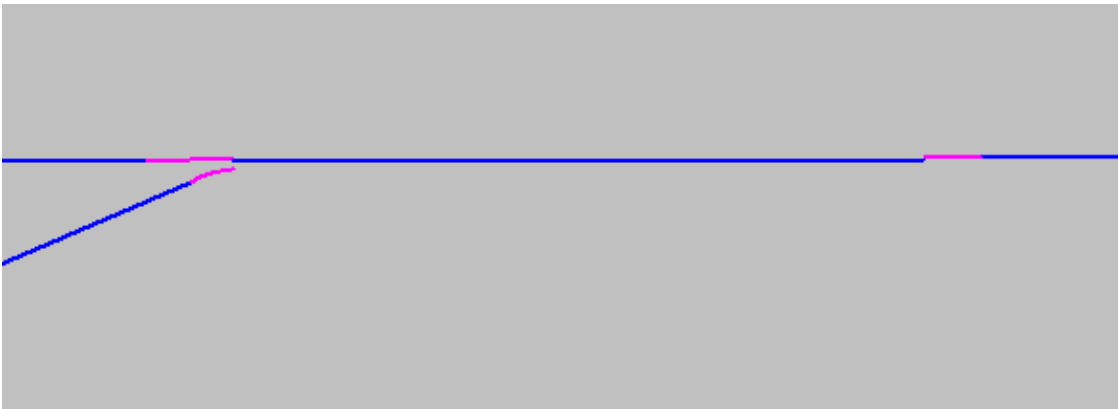


Figure 7: Designed VISSIM Model Displaying Links (Blue) and Connectors (Pink)

Figure 8 is a schematic of these data collections points with the identifying names labeled next to each data collection point. These names are used when identifying/discussing results and data collection at a particular location.

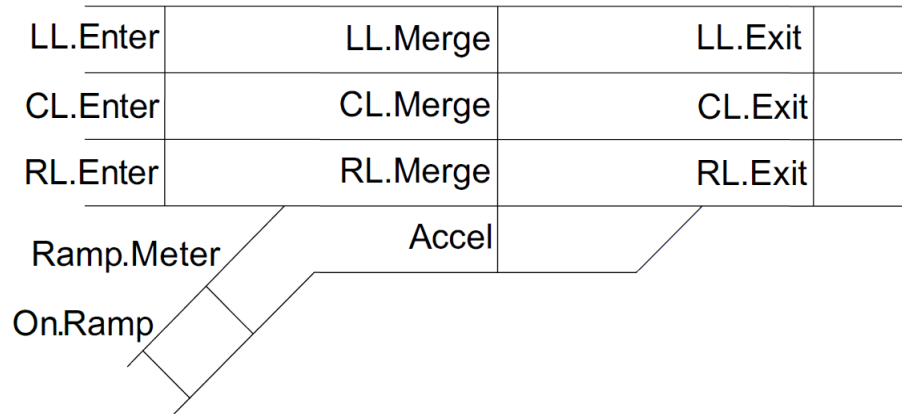


Figure 8: Schematic of Data Collection Points with Identifying Names (not to scale)

The next part of creating the VISSIM model includes changes to link and connector data as well as the how vehicles will operate within the model. As this is a freeway on-ramp it was important to change both the link and connector behavior types to freeway with free lane selection in order to incorporate the correct driving behavior parameters.

The next change made was to the lane change distance for the connector at the end of the effective merging area link. This value was changed from the default value of 656.2ft to a distance of 2,000ft. Having the lane change distance longer than the length of the effective merging area link ensured that vehicles from the mainline would not jump into the acceleration lane to try to gain positions on the mainline before the acceleration lane ended. This behavior is enforced based on the rules of the lane change distance which makes the driver consider every lane change when trying to reach the next connector after crossing the start of the lane change distance [23]. Furthermore, because

the acceleration lane ending is essentially a lane drop within VISSIM, making a lane change from the mainline to the acceleration is an unnecessary lane change and one that will not be permitted with the 2,000ft lane change distance.

Within VISSIM there are multiple vehicle types and the possibility to create new vehicle types with different accelerations, decelerations, weight, power, and lengths [20]. For the model, the standard car and heavy vehicle types were used. The percentage of heavy vehicles was 10% for both the mainline traffic and the on-ramp traffic inputs. Another modification was to set the desired speed distribution within VISSIM. The default speed distributions available ranged from a minimum speed of 55mph to maximum speed of 80mph for the standard car. This was adjusted to a smaller desired speed distribution of 68mph to 73mph. At this time, a separate desired speed distribution for the heavy vehicles of 60mph to 70mph was created due to their general lower mainline speeds.

Furthermore, it was also necessary to create two vehicle compositions, one for the mainline vehicle input and one for the on-ramp input, so that traffic entered the model in an appropriate manner depending on the entry location. For the mainline vehicle inputs, the vehicles should be traveling at the mainline speeds when they enter the model whereas, the on-ramp traffic will be entering the system at a much lower speed (36-43mph) as if they were coming from an arterial intersection. To bring the on-ramp vehicles up to the mainline speeds, desired speed decisions were placed such that by the time a vehicle was on the acceleration lane, its desired speed was equivalent to the mainline. Also, a left lane restriction for heavy vehicles on the mainline was put in place to keep trucks from riding in the left lane, which is a common practice in Georgia.

3.1.2 COM Simulation

The COM code used to run the simulations was written in Visual Basic. COM allows adjustments to vehicle attributes and VISSIM inputs enabling efficient

implementation of replicate trials. COM also allows for incorporation of code that enables VISSIM to mimic a desired behavior that otherwise is not possible within the VISSIM software. All simulations were run for 60 minutes with a simulation resolution of five time steps per simulation second. Traffic volumes and speeds were collected in one-minute intervals. The time before diffusion was set to the default 60 seconds for all simulations.

The traffic volumes simulated for the mainline were: 6,000veh/hr, 6,800veh/hr, 7,200veh/hr, and 7,800veh/hr. This is equivalent to: 2,000veh/ln/hr, 2,200veh/ln/hr, 2,400veh/ln/hr, and 2,600veh/ln/hr. Each of these mainline volumes were then simulated with three different on-ramp volumes: 600veh/hr, 800veh/hr, and 1,000veh/hr. Each of these volume scenarios were run multiple times, with each run having a different random seed (i.e. replicate trials). A copy of the COM code may be found in Appendix A.

3.2 Driver Behavior Parameter Analysis

VISSIM has unique simulation settings to create a more realistic merging behavior within the simulation as well as allowing the adjustment of certain driving and lane changing parameters. The goal of each of these analyzes is create realistic speed-flow curves. By adjusting parameters and settings, the shape of the speed-flow curve can be changed. Figure 9 shows a theoretical speed-flow curve.

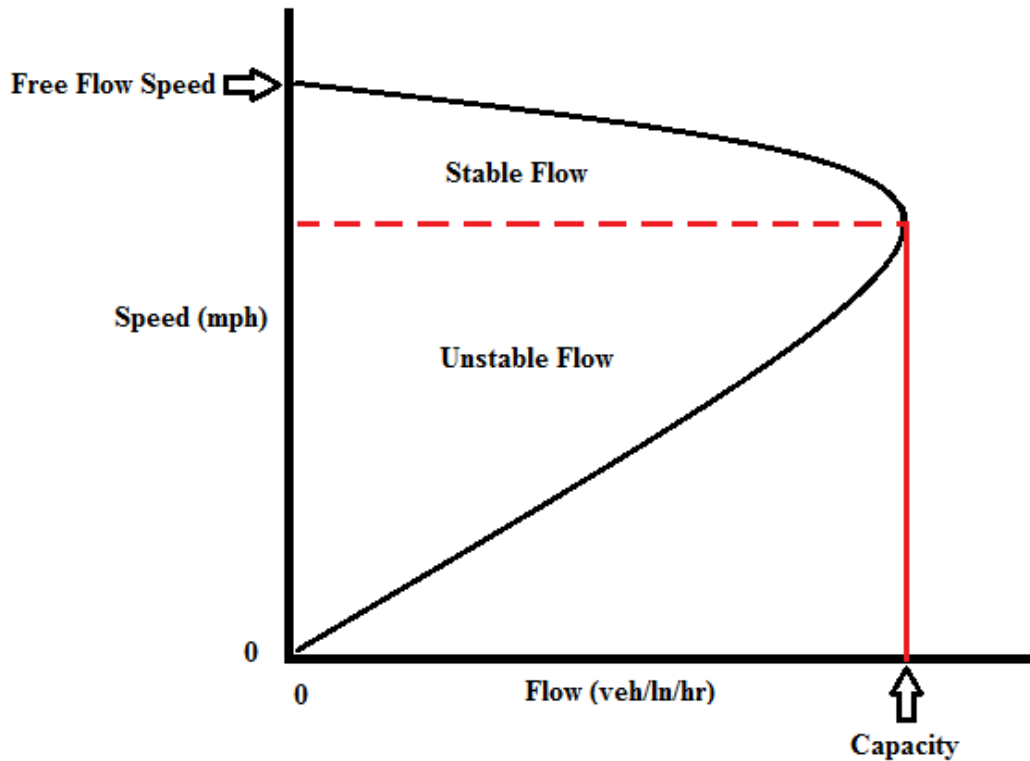


Figure 9: Theoretical Speed-Flow Curve

What can be seen from Figure 9 is that at low flow volumes traffic will be traveling at a free flow speed. As the flow is increased, the travel speed begins to slow down gradually, remaining in the upper half of the curve (called the stable flow regime) until the capacity of the freeway or travel lane is reached. At the point of reaching the capacity of the travel lane, speeds and flow volumes greatly decrease and enter the bottom half of the curve, which represents unstable flow and is where traffic congestion occurs. When actual speed and flow data points are collected and plotted, we can see this curve take shape. Figure 10 shows an illustration of a speed-flow plot using results from a VISSIM traffic simulation. From Figure 10, notice that the free flow speed is approaching 80mph and as the freeway reaches capacity (around 10,000veh/hr) the bottom half of the curve begins to take form showing that the vehicles are now in an unstable flow and the freeway is congested.

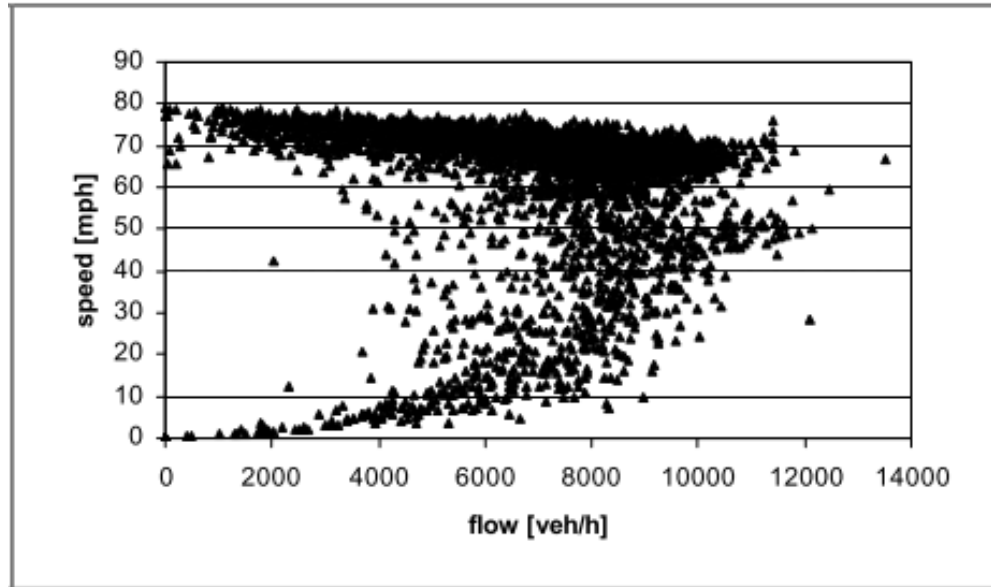


Figure 10: Speed-Flow Plot Using Results from a VISSIM Traffic Simulation [18]

This section will discuss which settings and features were studied to show how they change the shape of the speed-flow curve. Furthermore, a few brief results which changed how the simulations were run for the IDS simulations and ramp meter simulations will be discussed.

3.2.1 Advanced Merging and Cooperative Lane Change

Before starting with adjustments to the lane changing parameters, it is important to understand how the advanced merging and cooperative lane change features effected the simulation results compared to a strict default simulation where these two features are not selected. For this analysis, simulation runs with mainline volumes of 2,000veh/ln, 2,200veh/ln, 2,400veh/ln, and 2,600veh/ln were used and simulated with on-ramp volumes of 600veh/hr, 800veh/hr, and 1,000veh/hr. A total of five one-hour runs were completed for each traffic volume combination with randomly selected random seeds. Volume and speed data was collected in one-minute increments for each lane.

A total of four simulations were undertaken in this analysis: 1) A strict default simulation, 2) an advanced merging only simulation, 3) a cooperative lane change only simulation, and 4) a simulation where both the advanced merging and cooperative lane change were turned on. By taking the data obtained within each simulation, speed-flow curves were created which then could be compared side-by-side. Additionally, tables were created to compare the number of diffusions within each simulation and the number of remaining vehicles that did not enter the system.

The results of this analysis are presented in Chapter 4. However, from the advanced merging/cooperative lane change analysis it was determined that having both the advanced merging and cooperative lane change selected provided the best speed-flow curve. This in all subsequent analysis to be presented those features are turned on.

3.2.2 Safety Reduction Factor and Cooperative Braking

To further refine the shape of the speed-flow curves, multiple simulations were run with varying safety reduction factors and maximum cooperative braking values. Because the safety reduction factor reduces the desired safety distance when a vehicle changes lanes, meaning a smaller accepted gap size, and the cooperative braking value changes the willingness for another vehicle to allow a lane change to occur, these two parameters greatly contribute to the merging behavior. Other parameters are available to adjust, but for simplicity of the analysis were kept at their default values. This analysis was run with the same simulation setup used in the advanced merging/cooperative lane change analysis with the only variation being changes to the safety reduction factor and the cooperative braking value.

Following the parameter recommendations from the Oregon DOT Protocol for VISSIM Simulation, a set of safety reduction factors and cooperative braking values were selected. For the safety reduction factor, the values chosen were: 0.15, 0.25, 0.35, 0.45, 0.55, 0.65, and 0.75. The values chosen for the cooperative braking were: -8 ft/sec²,

-10 ft/sec², -12 ft/sec² and -14 ft/sec². Using these values, a comparison matrix of the speed-flow curves was created, simulating each combination of cooperative braking and safety reduction factor. Table 4 displays a blank structure of the speed-flow comparison matrix that will be presented in the results. Within each blank cell will be a speed-flow curve from the simulations run using the corresponding safety reduction factor and cooperative braking value.

Table 4: Structure of the Speed-Flow Comparison Matrix

Cooperative Braking (ft/sec ²)					
-14	-12	-10	-8		
				0.15	Safety Reduction Factor
				0.25	
				0.35	
				0.45	
				0.55	
				0.65	
				0.75	

3.3 Brief Observations of Simulation Process

Before moving forward with the analysis of the Incremental Desired Speed algorithm, there were two observations that arose resulting in adjustments to the simulation process. The first observation involved the need for an increased number of simulations runs for the lower volume scenarios. The second observation was a comparison of the 2,400 veh/ln and 2,600 veh/ln volume scenarios and how the results for each are very similar.

3.3.1 Importance of Multiple Simulation Runs for Lower Traffic Volumes

When performing the analysis on the affects different safety reduction factors and cooperative braking parameters speed-flow plots were generated for each mainline volume. When considering the 2,000veh/ln speed-flow comparison matrix, with 1,000 vehicles entering from the on-ramp, there was not a clear trend or pattern of the plots. Some plots showed vehicles in congestion and other plots did not, with no pattern related to the volumes. Figure 11 is the speed-flow comparison matrix for the 2,000veh/ln volume at the RL.Merge data collection point with varying safety factors and cooperative braking values. Each individual plot consists of five one-hour runs with data collected in one-minute increments.

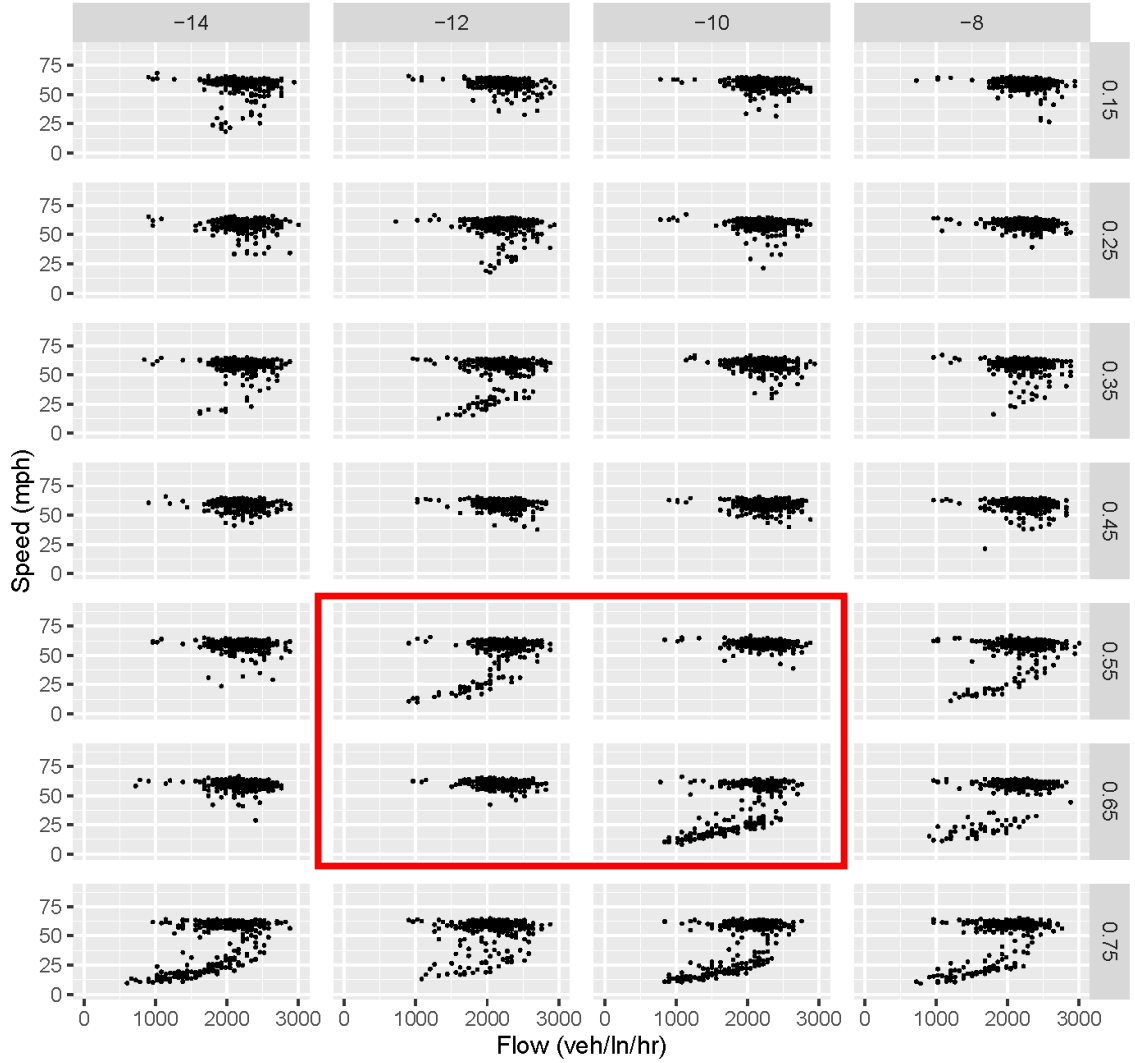


Figure 11: Speed-Flow Comparison Matrix for 2,000veh/ln at the RL Merge with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

Reviewing the plots within Figure 11 inconsistencies are seen. For example, consider the plots within the red box of Figure 11, an inverse in how these plots appear with and without the bottom of the curve can be seen.

It was suspected that even though all five of the simulation runs for each plot used a different randomly selected random seed, five replicates were insufficient to capture infrequent congestion, thus showing some plots with congestion and other showing a well running system.

To test this concern, the number of simulation runs for each plot was increased from 5 to 30 and the results were then plotted. Figure 12 shows the results of 30 replicate runs for each safety factor and cooperative braking combination.

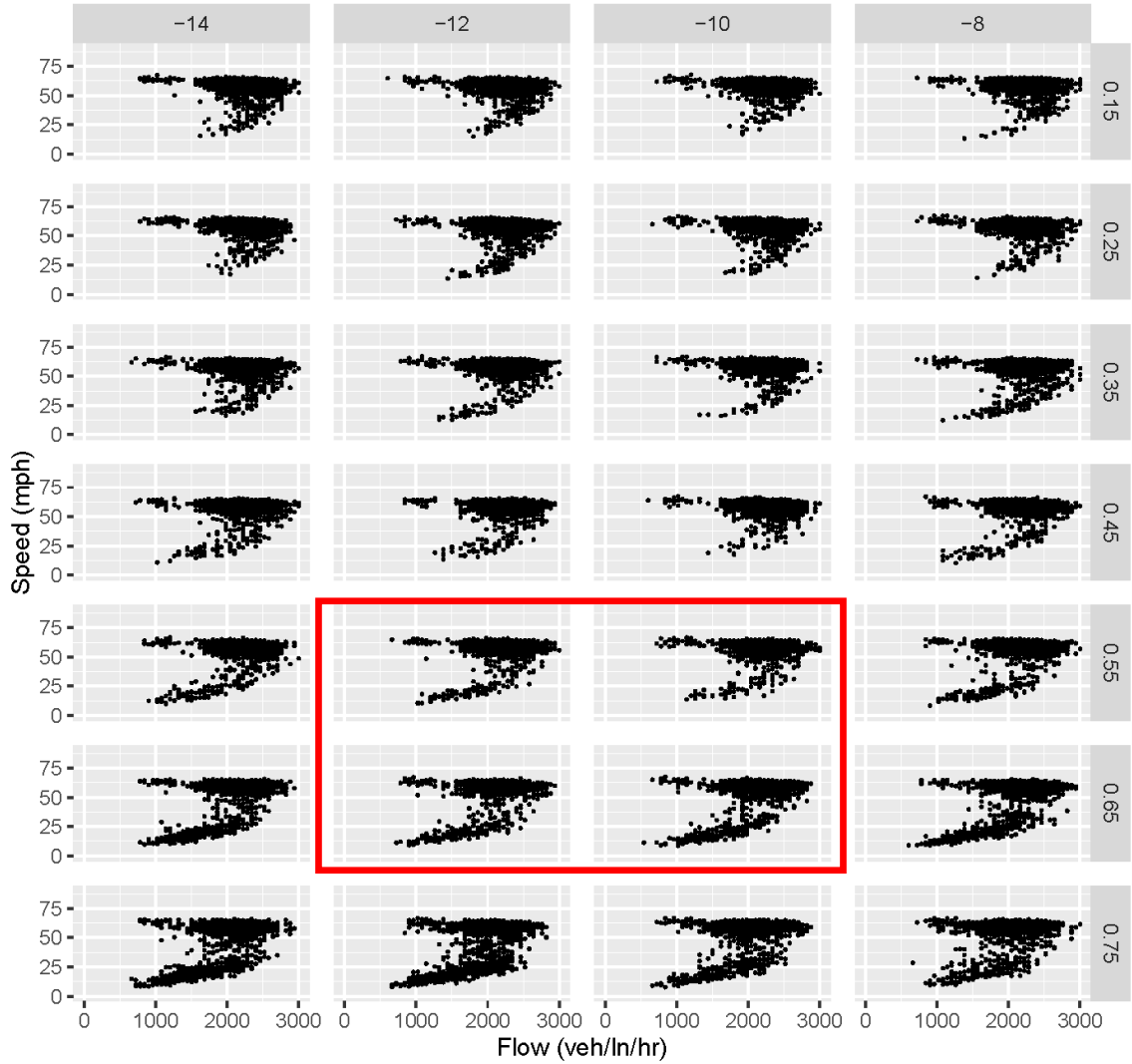


Figure 12: Speed-Flow Comparison Matrix for 2,000veh/ln at the RL.Merge with Varying Safety Factors and Coop. Braking (30 Runs, On-Ramp: 1,000vehs)

What can immediately be seen is that by increasing the number of replicate runs to 30, there is congestion for every safety factor and cooperative braking scenario.

Furthermore, when considering the same group of plots from Figure 11, which are again denoted by a red box, there is no longer is an inverse and the plots appear consistent.

To further explore the impact of replicate trials the number of simulation runs that produced a data point that showed congestion was determined. Based on the results, data points that fell below 37 mph were considered to be congested. Table 5 shows the number of runs that produced at least one data point below 37 mph. From Table 5 it is seen that of the total 30 runs, typically one-half to one-third produced a data point below 37 mph. Further investigation revealed that on approximately 95-99% of all the plotted data points were above the congested region. Thus, congestion at the lower mainline volumes is minimal but possible and should be taken into accounted. Thus for subsequent analysis the number replicate runs was increased.

Table 5: Number of Replicate Runs out of 30 that Produced at Least One Data Point Below 37mph

Cooperative Braking (ft/sec ²)					
-14	-12	-10	-8		
15	19	15	12	0.15	Safety Reduction Factor
18	18	14	14	0.25	
14	11	15	14	0.35	
14	10	14	12	0.45	
11	11	13	8	0.55	
15	14	12	18	0.65	
18	20	14	15	0.75	

3.3.2 Comparison of 2,400 veh/ln and 2,600 veh/ln

When continuing to perform the analysis on the effects of different safety reduction factor and cooperative braking combinations, it was observed that the 2,400 veh/ln and 2,600 veh/ln speed-flow curves were very similar. Figure 13 and Figure 14 show the speed-flow comparison matrixes for 2,400 veh/ln and 2,600 veh/ln volumes at the RL.Merge data collection point with 1,000 vehicles entering from the on-ramp respectively.

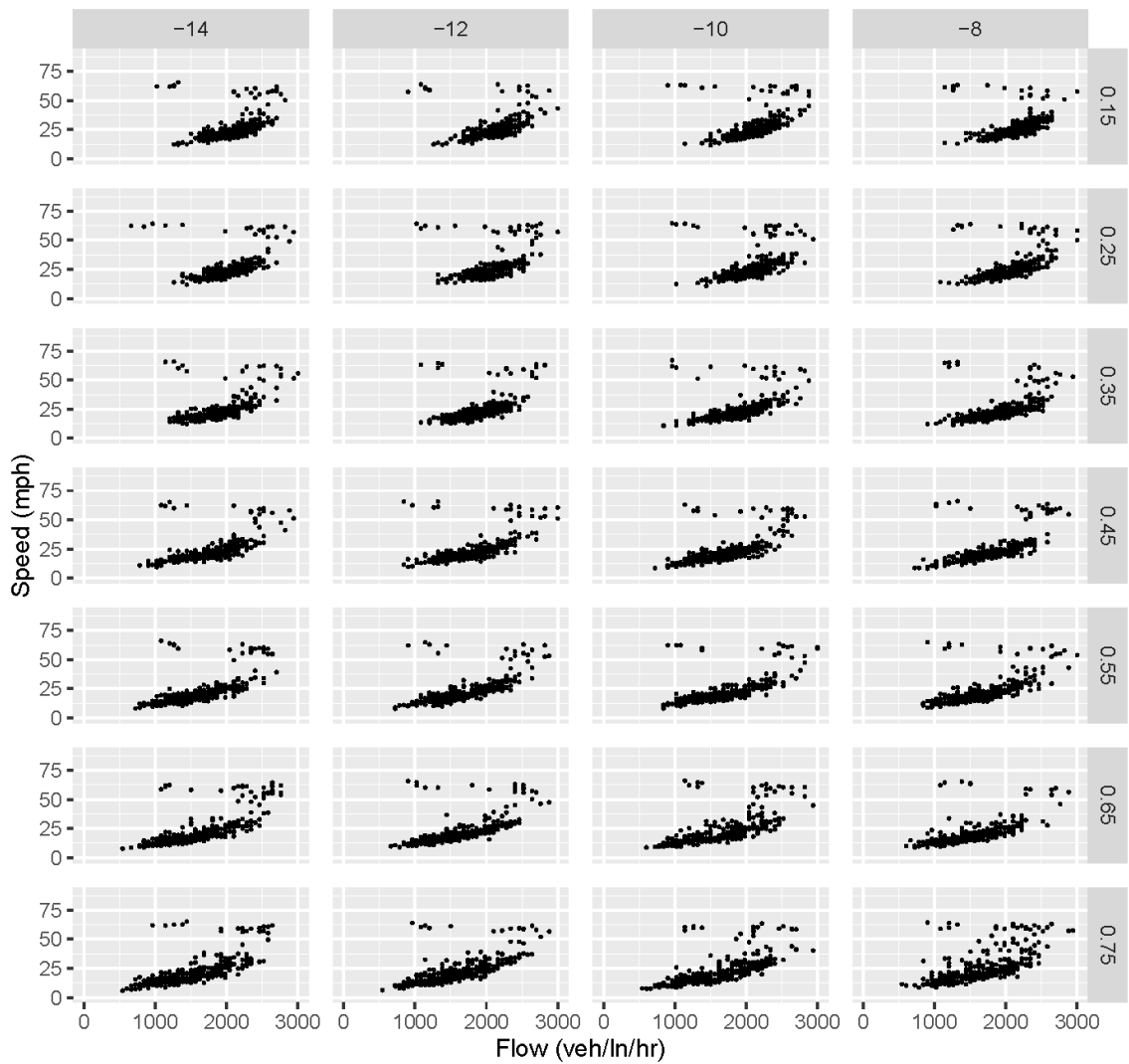


Figure 13: Speed-Flow Comparison Matrix for 2,400veh/ln at the RL.Merge with Varying Safety Factors and Coop. Braking (On-Ramp: 1,000vehs)

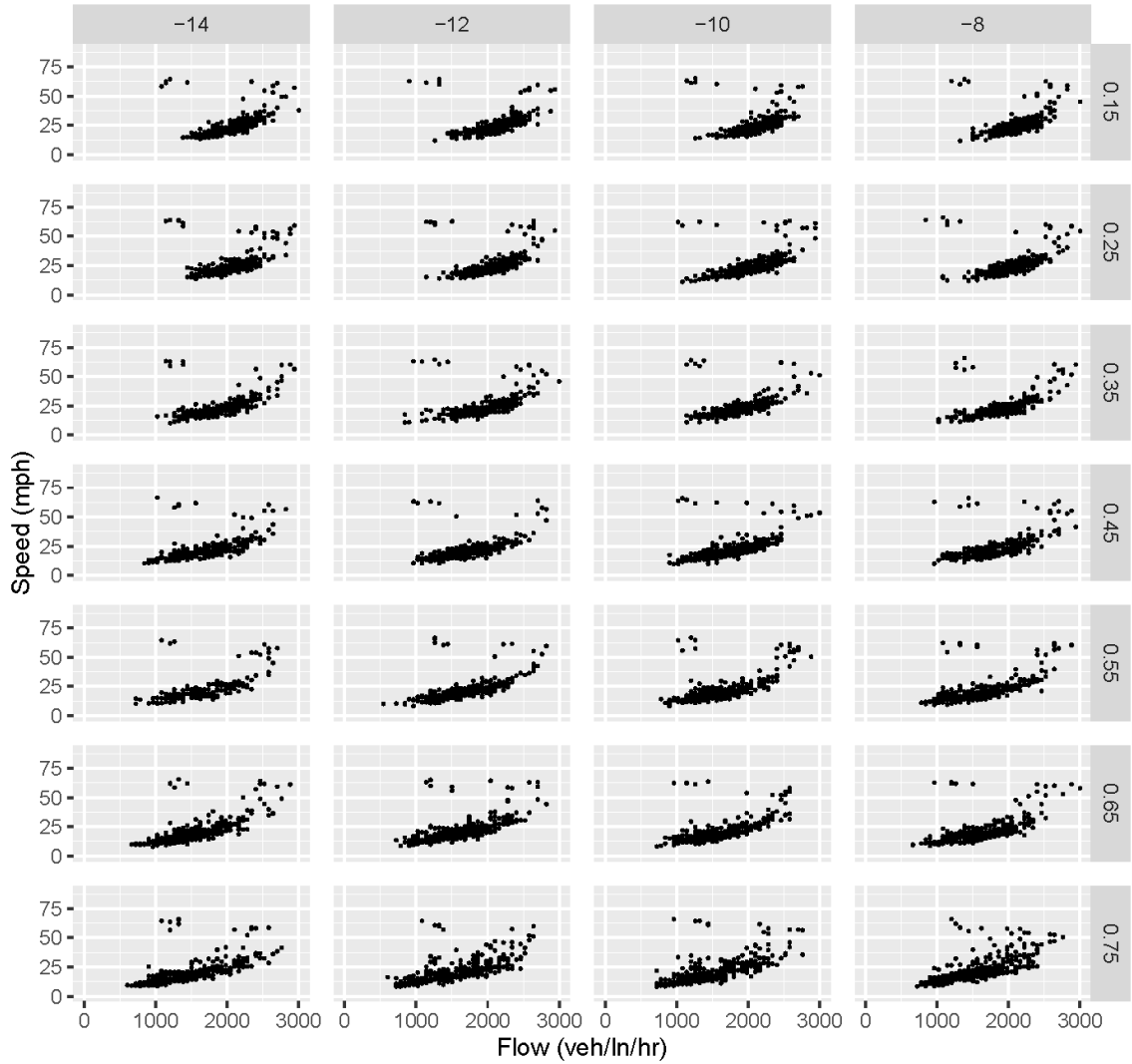


Figure 14: Speed-Flow Comparison Matrix for 2,600veh/ln at the RL Merge with Varying Safety Factors and Coop. Braking (On-Ramp: 1,000vehs)

A comparison of Figure 13 and Figure 14 shows that the speed-flow curves for these two mainline volumes are very similar in shape and location of the data. Due to this similarity, the 2,600veh/ln mainline volume was removed from the remaining analyses. The benefit of this was a faster simulation run time having only to simulate three mainline volume scenarios.

3.4 Incremental Desired Speed Algorithm

When viewing the VISSIM simulations from the previous analysis, a common issue occurred where the on-ramp traffic would queue up at the end of acceleration lane and could not merge onto the mainline. Eventually, the queue would reach the beginning of the on-ramp. Figure 15 shows an example of this occurring where the cars colored white are on the acceleration lane and are continually queueing back on the on-ramp.

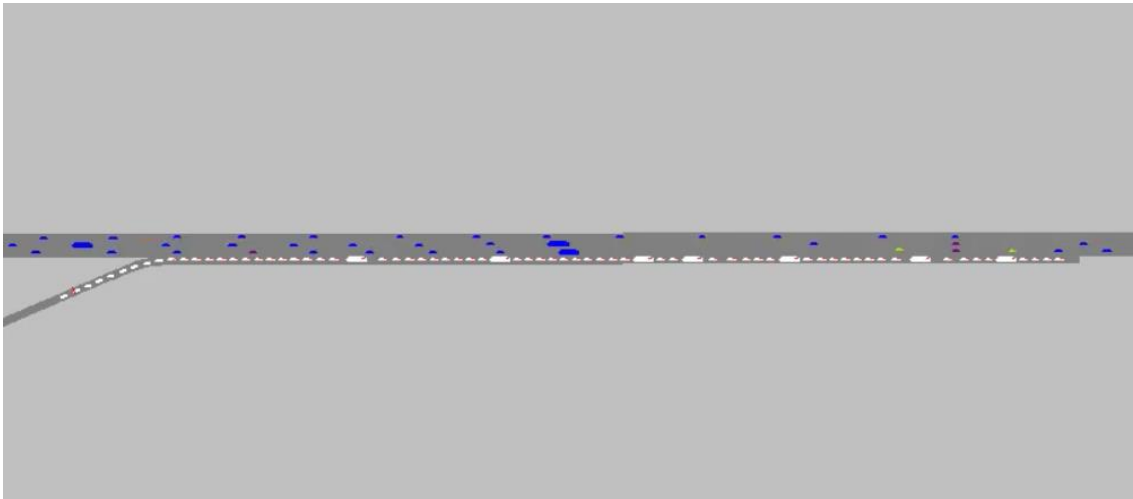


Figure 15: Queueing of the Acceleration Lane

The process that creates the queue seen in Figure 15 is that initially one or two cars will make it to the end of the acceleration lane before finding a suitable gap to merge into. These vehicles will slow to a stop at the end of the acceleration lane and then not be able to merge into traffic because the speed differential between their vehicle and the vehicles in the adjacent right lane is too large. Compounding the issue, as more cars join the queue at the end of the acceleration lane, the queue will grow faster since the available length for a vehicle to accelerate and merge into the freeway lane shortens with every preceding car that became a part of the queue. Once the queue has spilled back and up the on-ramp, cars primarily leave the queue through the diffusion process, one car every 60 seconds. For vehicle to successfully merge from the acceleration lane to the freeway

lane it is necessary to reduce the speed differential between the traffic streams. The Incremental Desired Speed (IDS) algorithm was developed for this purpose.

It is readily observed in the field that if a queue of cars has formed and they are stopped in the acceleration lane, a significant subset of mainline cars will not be willing to travel at free flow speeds in the adjacent lane for the fear of a vehicle jumping out of the queue into their lane. An analysis on the reduction of the effective capacity of the I-85 HOV lanes related to the general purpose lanes indicated such behavior. From the analysis, when the travel speeds within the HOV lane were between 15mph and 40mph the speed differential between the adjacent lane ranged from 0mph to 20mph respectively [24]. This result demonstrated that drivers in the HOV lane had a limit to the speed difference they were willing to except and travel with next to their neighboring lane [24]. VISSIM currently does not have a built in setting or feature to recreate this behavior. Thus, using COM was essential to recreate the behavior.

Within the VISSIM software there is a COM interface in which there are multiple objects that have several attributes that can be accessed and changed during a simulation. Within the IDS algorithm COM is utilized to access the links and vehicle objects. By using the links object, vehicle data can be gathered by link number. Furthermore, using vehicle attributes within the vehicle object, the lane position, link coordinate, and vehicle speed can be collected and adjusted.

The previous calibrations performed did help in prolonging this queuing issue from occurring after adjustment. The IDS algorithm is the next step in relieving the problem and allowing cars within the acceleration lane queue to merge onto the mainline. The IDS algorithm does not solve the issue of the queue forming from high traffic demand, instead it increases the likelihood of a vehicles within the queue successfully merging by ensuring that the speed differential between the acceleration lane and freeway lane is reduced.

The first step of the IDS algorithm is to calculate the average speed of the vehicles within the second half of the acceleration lane once there are four or more cars within the second half. The reason for having the number of cars set at four or more is to ensure that the code will have a higher probability impacting freeway speeds only when a queue begins to form in the acceleration lane. The number of cars needed to determine the acceleration lane speed is user defined number.

Once IDS has calculated an average speed, the next step is to compare that speed to a user defined “threshold” speed. If the calculated average speed is below this threshold speed then the code will continue forward; otherwise, no adjustment to the mainline speed will be made. For this analysis three threshold speed values were tested: 10mph, 20mph and 30mph.

If IDS has determined that the calculated average speed is below the user defined threshold speed, then the next step is to adjust the desired speeds of the mainline vehicles lane-by-lane by a user defined speed increment. The right most lane mainline speed (i.e., the lane adjacent acceleration lane) will be set (through the desired speed attribute in VISSIM) to the acceleration lane speed plus the user selected speed increment. Each subsequent adjacent lane desired speed will be set to the adjacent right-lane desired speed plus one speed increment. For example, assume a threshold value of 30mph has been set along with a speed increment of 10mph for a freeway with three travel lanes in the direction of interest. If during a simulation run IDS calculates an average speed of 20mph for 5 cars present in the second half of the acceleration lane IDS will change the mainline desired speeds. The freeway right lane vehicles will have a new desired speed of 30mph, the center lane 40 mph, and the left lane 50 mph. Three speed increments were tested in this analysis: 10mph, 15mph, and 20mph.

An important feature within the desired speed adjustment portion of IDS is that the center lane and left lane have a maximum possible desired speed that is the speed limit of the mainline (or set desired speed free flow conditions). Even by having a small

speed increment of 10mph, with sufficient travel lanes on the mainline the new desired speed could be higher than the speed limit if the IDS did not include this constraint. For our three-lane freeway the maximum new desired speed that could be placed on the center and left lane is 65mph.

A benefit of having the threshold speed and the speed increment as user defined variables is that the Incremental Desired Speed algorithm can be calibrated to site specific observed behavior. Also, as the IDS code is associated with a link it can be used to calibrate multiple merge areas with a model, using different thresholds and speed increments. The IDS algorithm can be seen from line 63 to line 120 of the COM code within Appendix A.

3.5 Implementation of a Ramp Meter

“VISSIM can accommodate a broad range of ramp metering algorithms [21].” These include simple single lane fixed timing all the way to complex detection of the freeway traffic data to determine the metering rate. For the model in this analysis a simple fixed time ramp meter was implemented to demonstrate how a ramp meter can be put in place and for proof of concept that a ramp meter increases vehicle flow and travel speeds. The setup and programming of the ramp meter were taken from Appendix F of the Oregon DOT Protocol for VISSIM Simulation.

The ramp meter consists of a single signal head along with an approach detector (16ft long) and a departure detector (6.5ft long). The signal head is coded using a file written using VISSIM’s VAP signal control language and is accompanied with a PUA file that contains the signal and interstate definitions [21]. Appendix B of this thesis contains the code for both the VAP file and the PUA file.

Once having both files created the two files are then linked to VISSIM’s signal controller in the same way one would set up an actuated signal controller in VISSIM [21]. Within the signal control settings, the VAP file is assigned in the LOGIC FILE field

and the PUA file is assigned within the INTERSTATE FILE field [21]. For the signal to turn green and let a vehicle through there are three conditions defined within the VAP file that must be met at the same time [21]:

1. A vehicle is detected on the approach detector,
2. The departing vehicle is no longer detected on the departure detector, and
3. The ramp meter signal has been red for at least three seconds (based on a user defined threshold of three seconds).

The user defined threshold can be adjusted to achieve the desired ramp metering capacity [21]. A larger value will reduce the capacity while a shorter value will increase it.

Figure 16 displays the setup of the ramp meter within VISSIM model in this study. To perform this analysis, the same simulation performed during the Incremental Desired Speed algorithm analysis, with a threshold of 30mph and a speed increment of 15 mph was used with the only difference being a ramp meter was added. The results of the two simulations will be used to compare the speed-flow curves before and after the ramp meter was turned on.

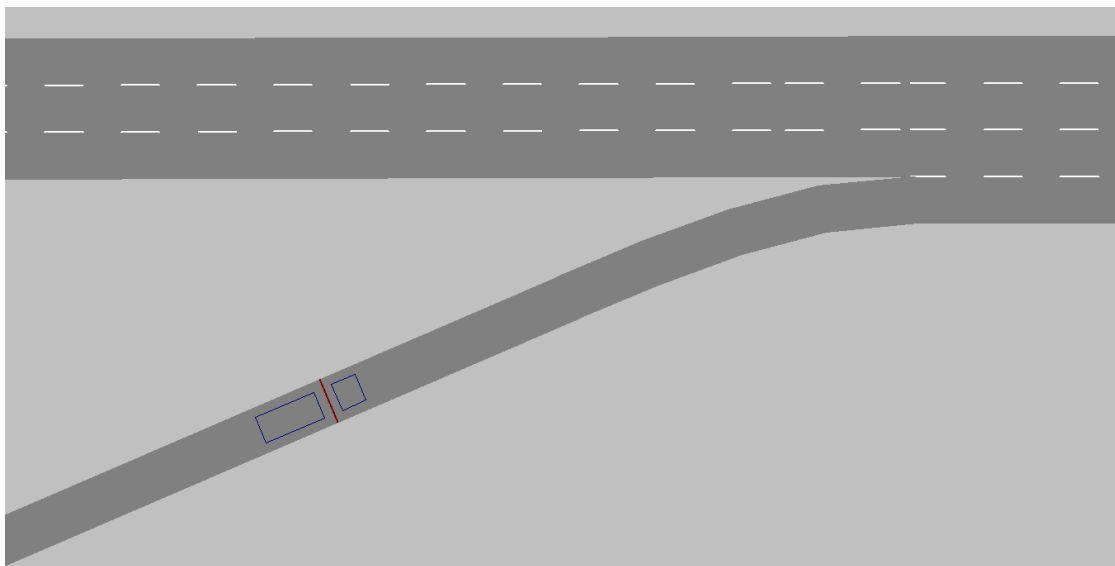


Figure 16: Ramp Meter Model Setup

CHAPTER 4

RESULTS

Chapter 4 will present the results from each of the four analyses performed and how the shape of the speed-flow curves changes. The order of the results is as follows: 1) the analysis of advanced merging and cooperative lane change, 2) the analysis of the adjustments made to the safety reduction factor and cooperative braking parameters, 3) the analysis of the Incremental Desired Speed algorithm, and lastly 4) the comparison of non-ramp metered and ramp metered case.

4.1 Analysis of Advanced Merging and Cooperative Lane Change

For this analysis four alternatives were completed: 1) A strict default simulation, 2) an advanced merging only simulation, 3) a cooperative lane change only simulation, and 4) a simulation where both the advanced merging and cooperative lane change were turned on. Gathering the data from the merge and entering data collections points as well as from the on-ramp data collection point, a comparison of the speed-flow curves can be made. Tables were also created to compare the number of diffusions and the number of remaining vehicles that were reported in the error files for each simulation.

Figure 17 is a speed-flow comparison matrix presenting all of the data that was collected for all mainline volume scenarios at the right lane merge (RL.Merge) data collection point from all four simulations. The top left of Figure 17 contains the strict default simulation data, the top right is the advanced merging (AdvMerge) only simulation, the bottom left is the cooperative lane change (CLC) simulation, and the bottom right is simulation where both the advance merging and cooperative lane change were turned on. The focus of the data in Figure 17 should be on the overall shape of the speed-flow curves.

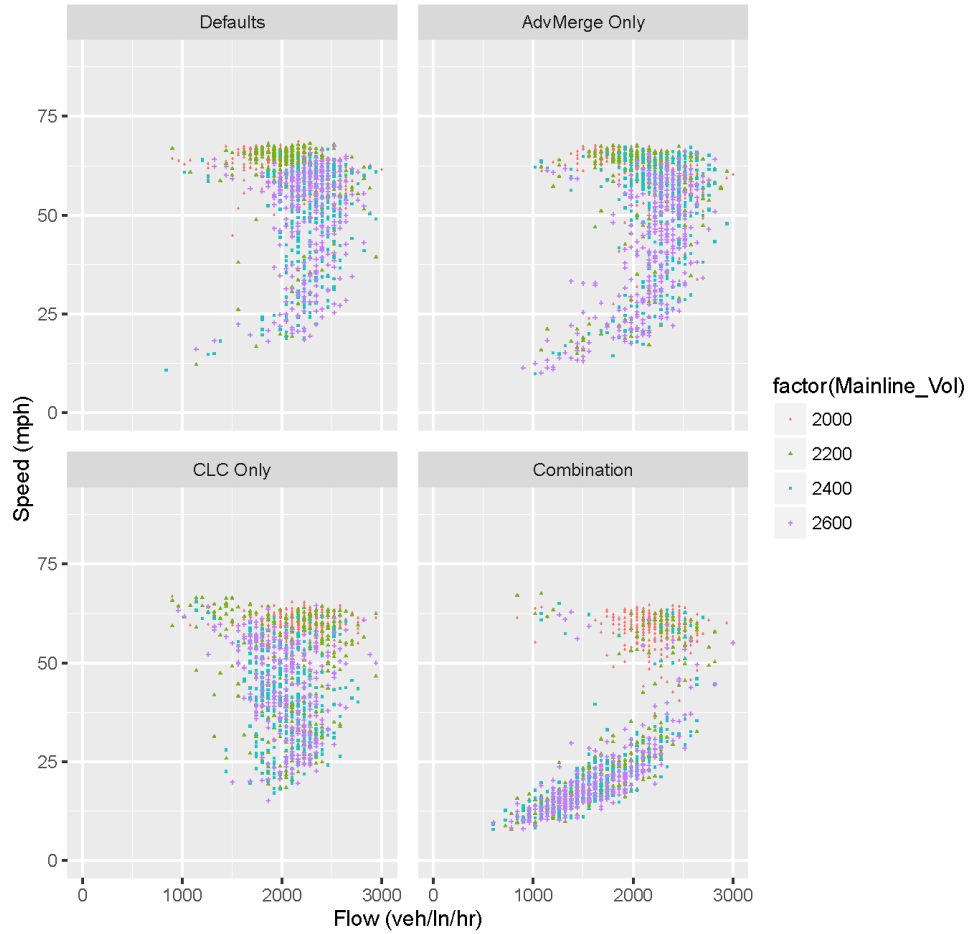


Figure 17: Speed-Flow Comparison Matrix for Varying AdvMerge and CLC Settings at All Mainline Volumes at the RL Merge (On-Ramp: 1,000 vehs)

Through visual inspection of Figure 17 it can be seen that when the combination of advanced merging and cooperative lane change are used that the speed-flow curve fits the theoretical model of a speed-flow curve well. While the advanced merging only simulation (and to some degree the default simulation) shows a similar speed-flow curve, it was known beforehand that the 2,400 veh/ln and 2,600 veh/ln mainline volumes are approximately at or above the capacity of the modeled freeway and should consistently cause congestion, falling into the bottom half of the curve (unstable flow). The advanced merging results have a large portion of the 2,400 veh/ln and 2,600 veh/ln mainline volumes present in the upper portion of the curve (stable flow). The main reason this occurred is that the on-ramp failed, with traffic queuing on the acceleration lane and no

longer merging onto the freeway while the mainline vehicles traveled at close to free flow speeds.

Figure 18, the speed-flow comparison matrix from the on-ramp data collection point (On.Ramp), shows that the on-ramp spillback due to failure to merge reached the most upstream part of the ramp during the advanced merging only simulations as well as during the defaults and CLC simulations. Those simulations contrast from what is seen within the combination simulation where the data points never fall below an average speed of 35mph, which is 1mph less than the set desired speed for the on-ramp vehicle input.

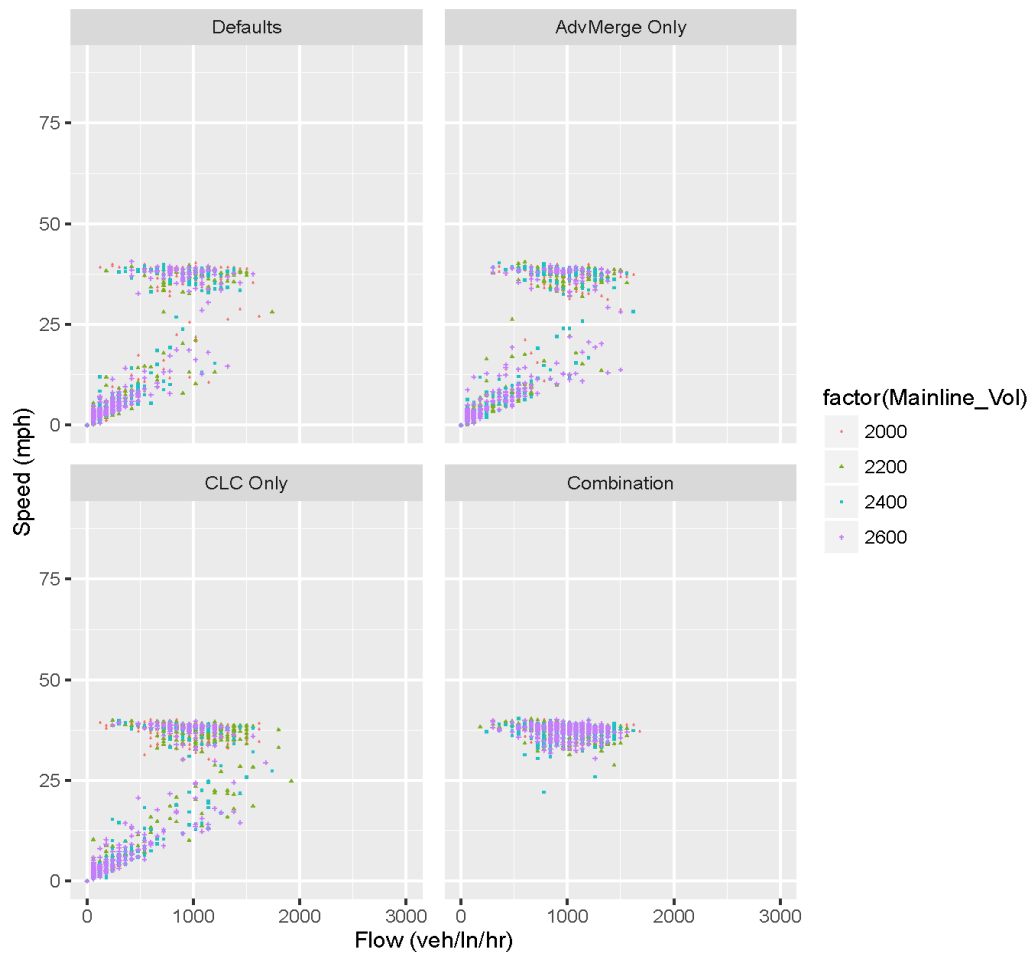


Figure 18: Speed-Flow Comparison Matrix for Varying AdvMerge and CLC Settings at All Mainline Volumes at the On.Ramp (On-Ramp: 1,000vehs)

Figure 19, the speed-flow comparison matrix from the acceleration lane, also shows considerable congestion during the advanced merging only simulations as well as during the defaults and CLC simulations while the combination simulation illustrates a smoother merging process.

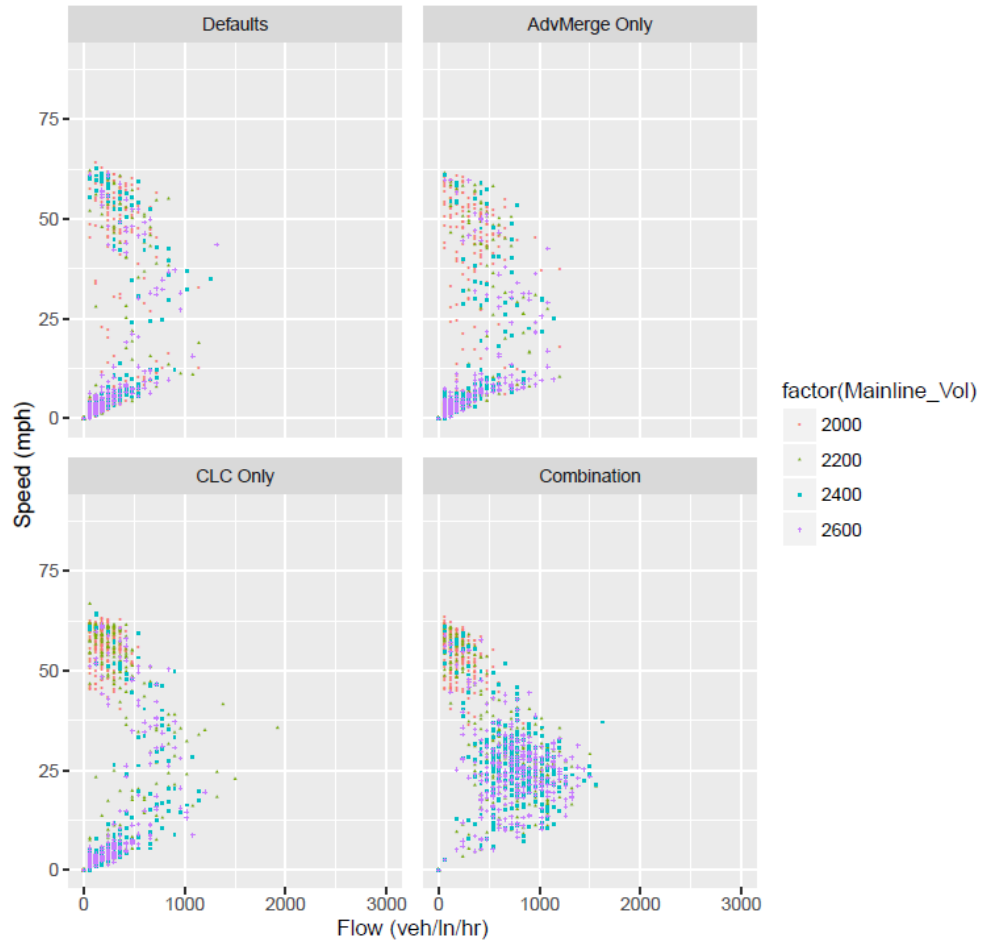


Figure 19: Speed-Flow Comparison Matrix for Varying AdvMerge and CLC Settings at All Mainline Volumes on the Acceleration Lane (On-Ramp: 1,000vehs)

Appendix C contains additional speed-flow comparison matrices for varying AdvMerge and CLC settings at all mainline volumes for the CL.Merge, LL.Merge, RL.Enter, CL.Enter and LL.Enter data collection points where congestion was present.

Table 6 shows the hourly average number of diffusions observed within all four of the simulations at different mainline and on-ramp volumes.

Table 6: The Average Number of Diffusions per Hour Observed

		Average Hourly Diffusions for Different VISSIM Settings			
		Default	Advanced Merging Only	Cooperative Lane Change	Combination of Both
Mainline Volume (vehs)	On Ramp Volume (vehs)				
6000	600	6.6	1.6	0.2	0
	800	24.8	2.4	0.2	0
	1000	24.4	20.6	1.4	0
6600	600	23.2	15.6	2.4	0.6
	800	31.8	26	10.2	2.4
	1000	32	24.6	14.2	2.8
7200	600	29.6	25.8	20.8	4.4
	800	28.6	29.2	21.4	4.2
	1000	33.4	28.8	19.6	4.4
7800	600	34	27.4	21.2	3.8
	800	32.2	28.4	22	5.4
	1000	34	28.8	21.2	4

Table 6 shows how the combination simulation has provided a better reflection of vehicles successfully merging into the mainline by reducing the number of diffusions. From left to right, the number of diffusions are greatly reduced.

Table 7 shows the average number of remaining vehicles that could not enter the model during the one hour run time. The definition of a remaining vehicle is a vehicle that was never physically able to be placed in the model. This means if a vehicle input of 500 vehicles was set and only 300 cars actually entered, then the number of remaining vehicles would be 200 and VISSIM would output that value in an error file.

Table 7: The Average Number of Remaining Vehicles per Hour Observed

		Average Hourly Remaining Vehicles for Different VISSIM Settings							
		Default		Advanced Merging Only		Cooperative Lane Change Only		Combination of Both	
Mainline Volume (vehs)	On Ramp Volume (vehs)	Mainline	On Ramp	Mainline	On Ramp	Mainline	On Ramp	Mainline	On Ramp
6000	600	0	0	0	0	0	0	0	0
	800	0	134	0	0	0	0	0	0
	1000	0	373	0	386	0	0	0	0
6600	600	0	169	4	47	0		32	0
	800	0	269	0	295	0	48	194	0
	1000	0	581	0	528	0	161	418	0
7200	600	198	140	262	78	200	96	573	0
	800	184	352	168	356	212	293	881	0
	1000	138	573	128	559	160	519	1132	0
7800	600	599	188	802	124	794	93	1129	0
	800	618	391	766	347	760	351	1582	0
	1000	610	601	685	550	686	519	1749	0

Reviewing Table 7, it can be seen that as the traffic volumes increased the number of remaining vehicles also increased. This is a result of the higher traffic demands approaching then exceeding capacity of the ramp junction. When moving left to right within Table 7, two things are noticeable: 1) the number of remaining vehicles is increasing on the mainline and 2) the number of remaining vehicles on the on-ramp is decreasing. The significance of this is that when there are remaining vehicles on the on-ramp, the on-ramp has failed and a queue has formed to the beginning of the on-ramp in the model. The combination setting has avoided the long queue from forming that far back. However, this result does not mean that the on-ramp did not fail and form a long queue, but simply that the queue did not reach the entry point of the ramp in the model.

4.2 Analysis of Safety Reduction Factor and Cooperative Braking

To further develop the shape of the speed-flow curves, multiple simulations were run with varying safety reduction factor values and maximum cooperative braking values, as described in Chapter 3. Gathering the data from the merge and entering data collections points as well as from the on-ramp data collection point, a comparison of the speed-flow curves can be made. Figure 20 is a speed-flow comparison matrix presenting all of the data that was collected for all mainline volume scenarios at the right lane merge (RL.Merge) data collection point from all 28 safety factor/coop braking simulations.

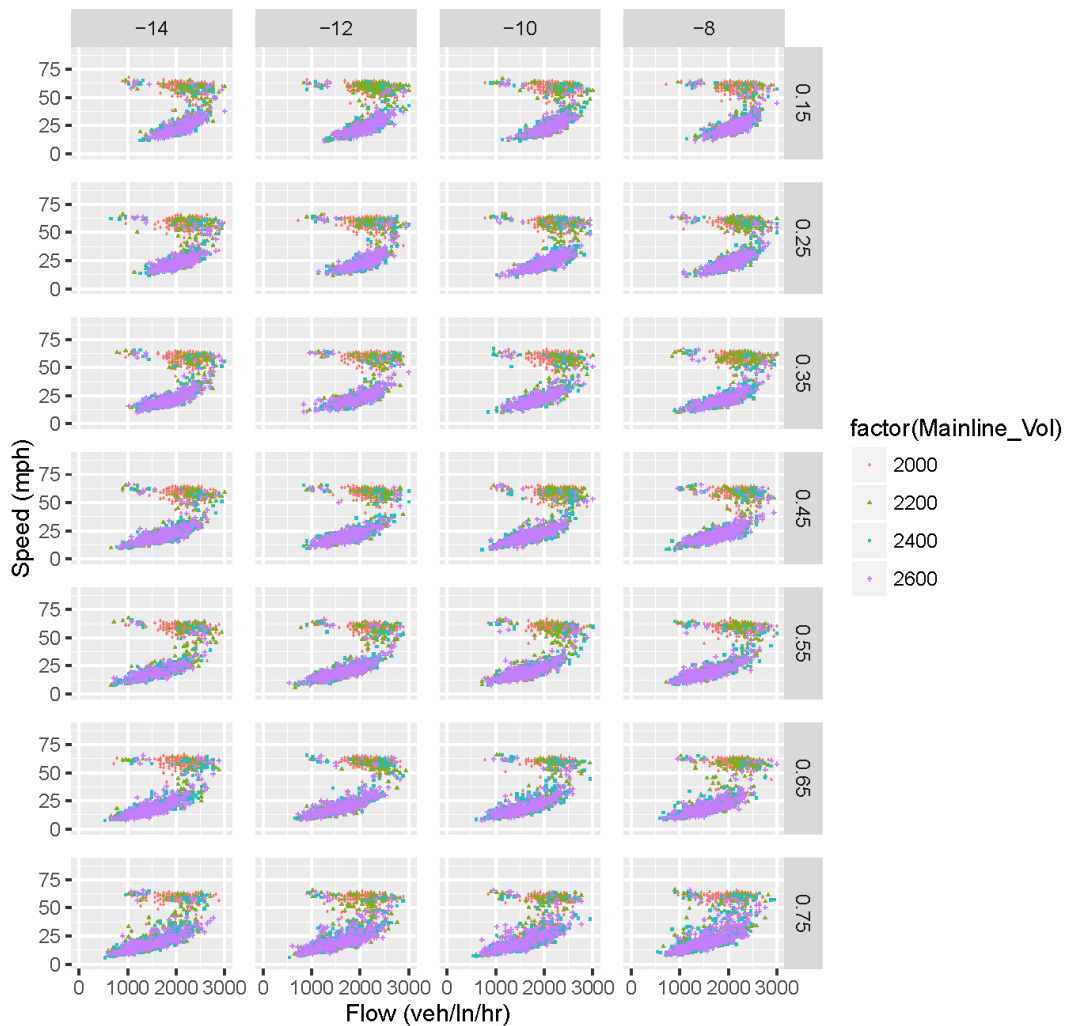


Figure 20: Speed-Flow Comparison Matrix for All Volumes at the RL.Merge with Varying Safety Factors and Coop. Braking (On-Ramp: 1,000vehs)

What can be seen from Figure 20 is that as the safety reduction factory increases from 0.15 to 0.75 the higher mainline volumes become more and more congested and both lower speeds and flow volumes were recorded. Additionally, to better understand the influence that the safety reduction factor and cooperative braking parameter have on the different mainline traffic volumes, each mainline volume has been plotted independently within its own speed-flow comparison matrix for the RL.Merge data collection point. A note about the 2,000veh/ln comparison matrixes that accompany this analysis is that they are created from a total of 30 one-hour runs whereas the other mainline volumes are created from 5 one-hour runs. An explanation for this can be found in Chapter 3, Section 3.3.1 of this thesis. Figure 21 is the data from the 2,000veh/ln run at the RL.Merge.

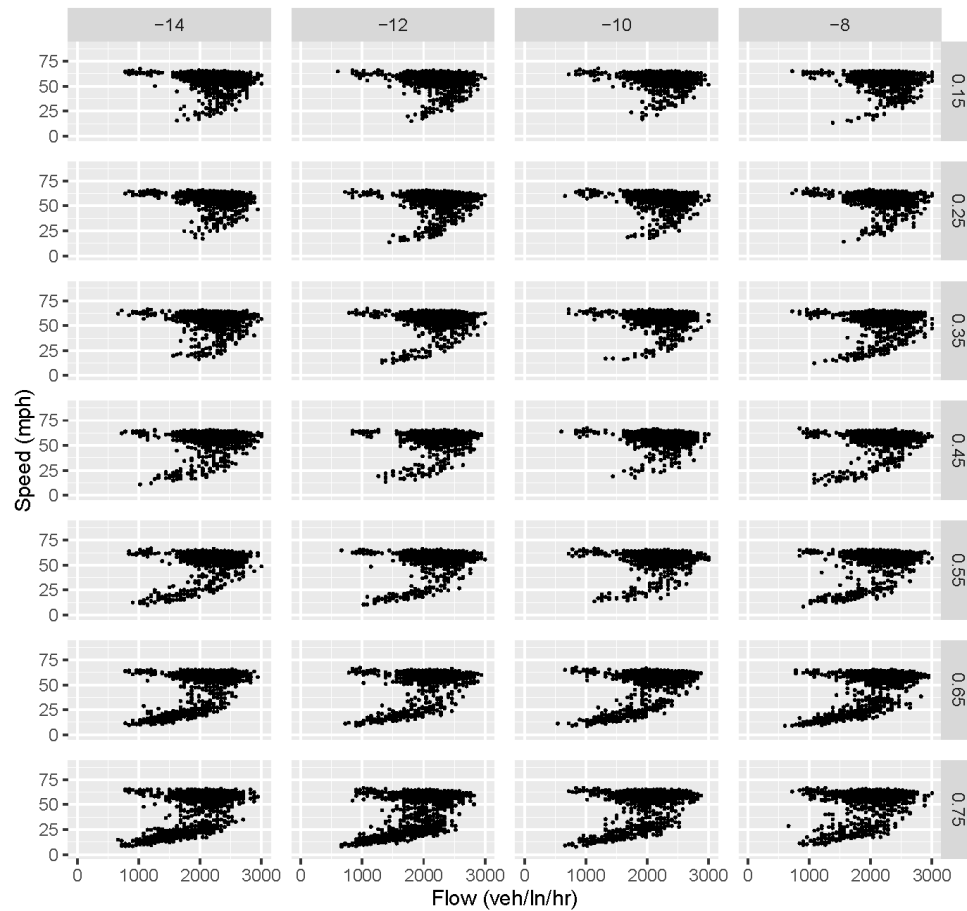


Figure 21: Speed-Flow Comparison Matrix for 2,000veh/ln at the RL.Merge with Varying Safety Factors and Coop. Braking (30 Runs, On-Ramp: 1,000vehs)

From Figure 21, it can be seen that as the safety factor increases the grouping of the data points within the unstable flow portion of the speed-flow curve moves closer to the origin of the plot. Figure 22 is the speed-flow comparison matrix for the 2,200veh/ln volume data at the RL.Merge data location point.

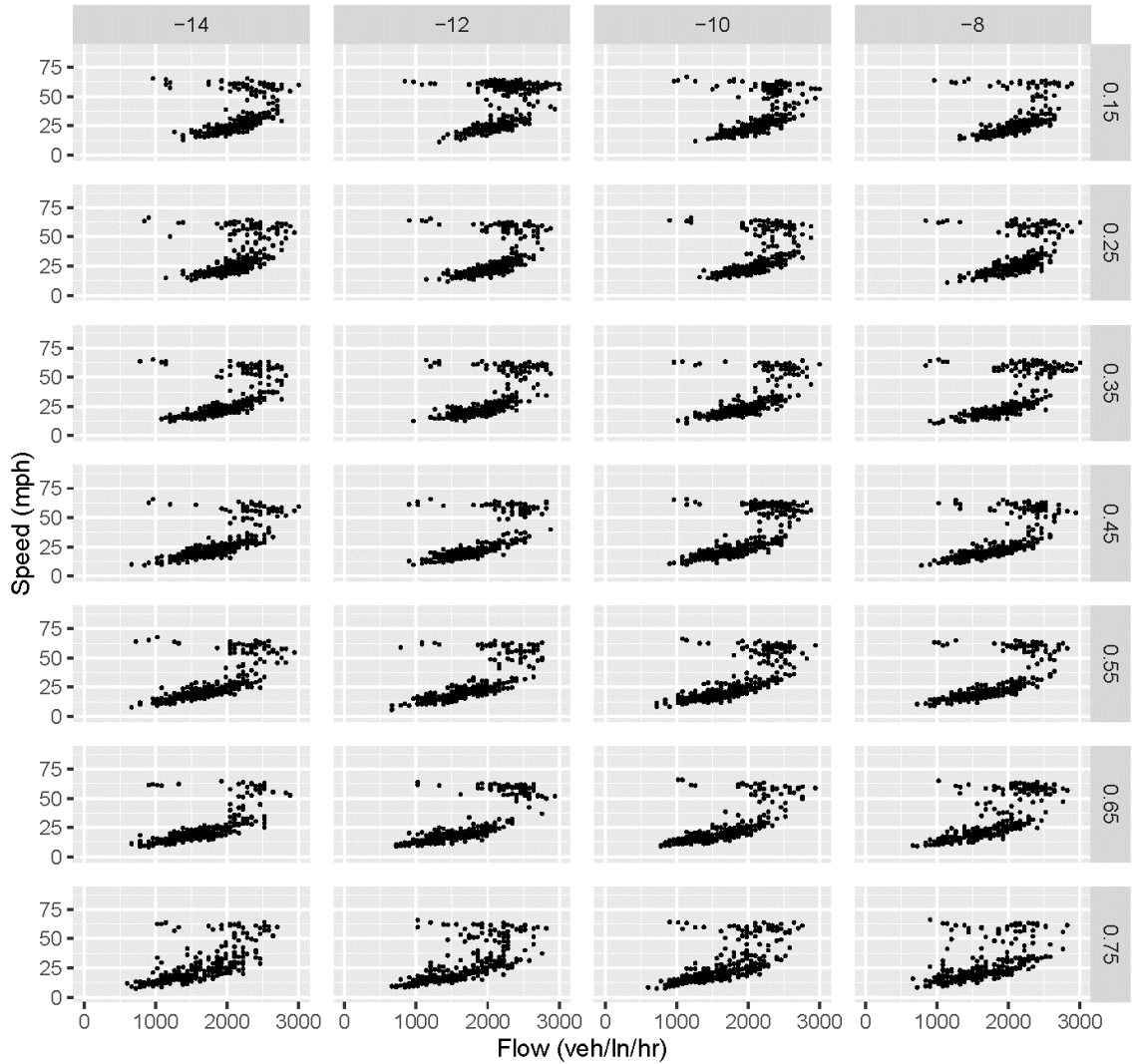


Figure 22: Speed-Flow Comparison Matrix for 2,200veh/ln at the RL.Merge with Varying Safety Factors and Coop. Braking (On-Ramp: 1,000vehs)

Similar to the 2,000veh/ln data, the 2,200veh/ln data show that the severity of the congestion increases as the safety reduction factor increases. However, there doesn't appear to be a large variation in the results as the cooperative braking changes.

Figure 23 and Figure 24 are the speed-flow comparison matrixes for the 2,400veh/ln volume data and 2,600veh/ln volume data respectively at the RL.Merge data location point.

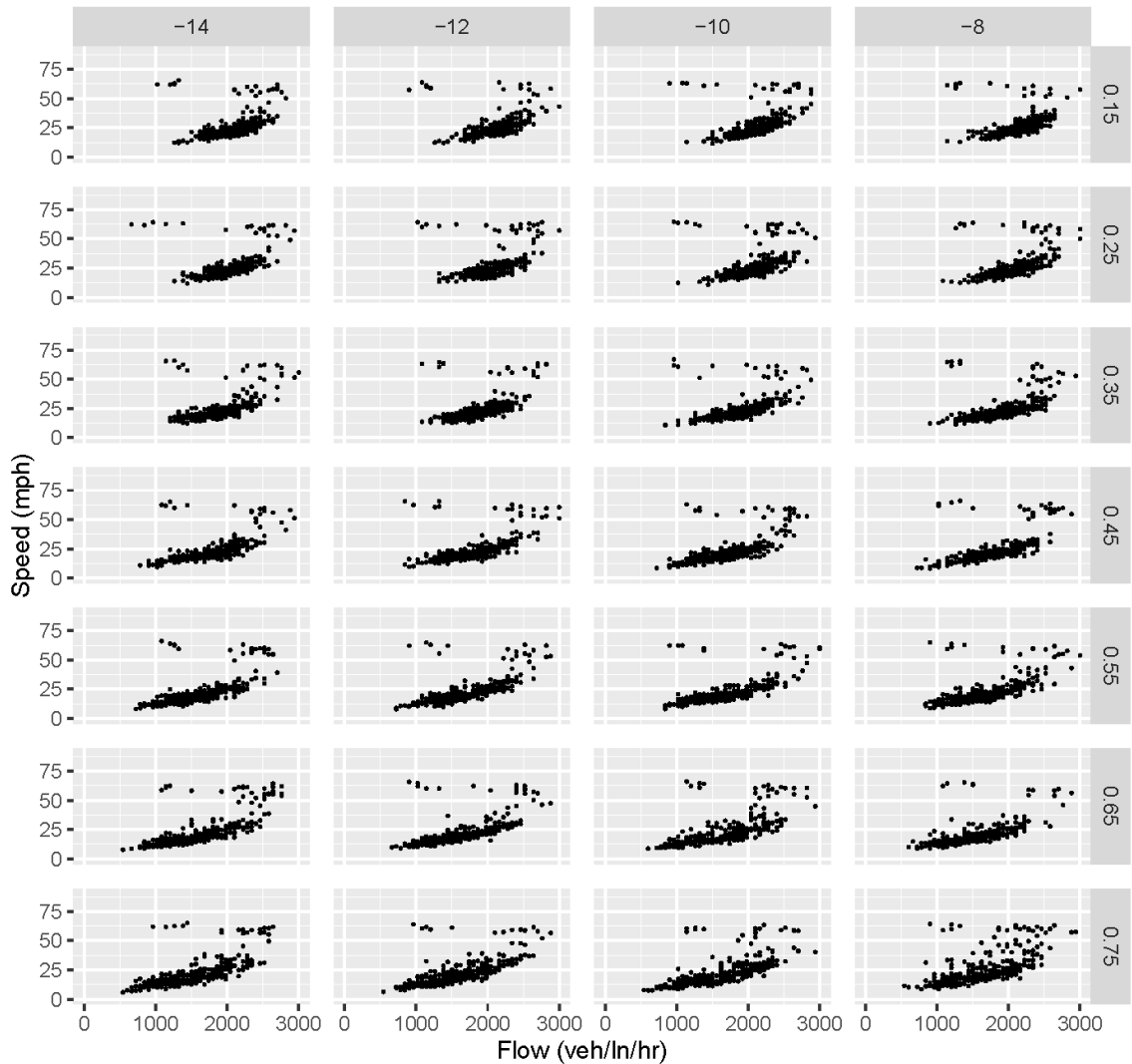


Figure 23: Speed-Flow Comparison Matrix for 2,400veh/ln at the RL.Merge with Varying Safety Factors and Coop. Braking (On-Ramp: 1,000vehs)

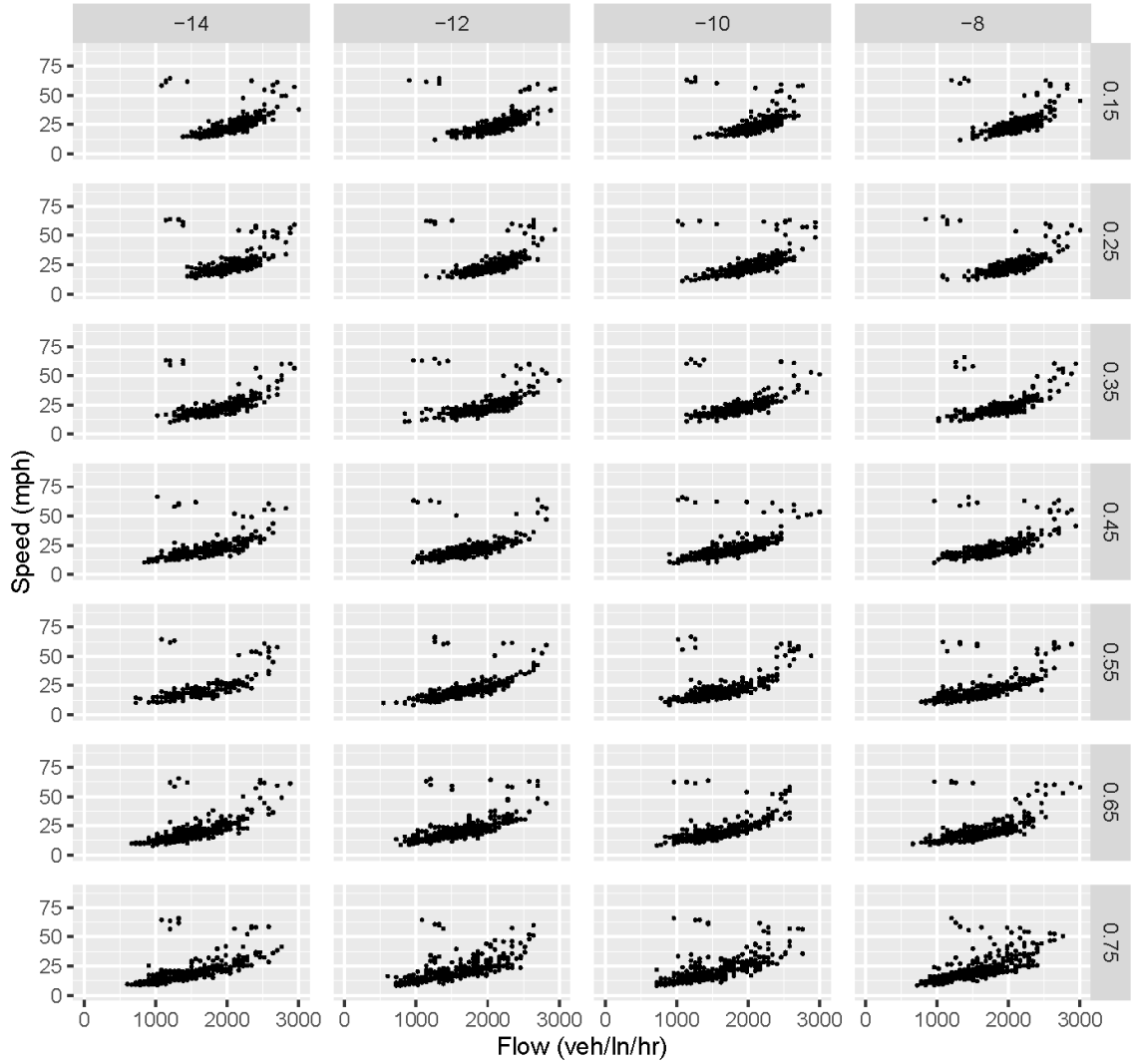


Figure 24: Speed-Flow Comparison Matrix for 2,600veh/ln at the RL.Merge with Varying Safety Factors and Coop. Braking (On-Ramp: 1,000vehs)

As seen with the lower mainline volume cases, the safety reduction factor has the bigger influence on the shape of the speed-flow than the cooperative braking parameter does for the 2,400veh/ln and 2,600veh/ln volumes. Appendix D contains additional speed-flow comparison matrices for varying speed reduction factor and cooperative braking settings for the CL.Merge, LL.Merge, RL.Enter, CL.Enter and LL.Enter data collection points.

To see the effect that the safety reduction factor and cooperative braking has on the on-ramp, Figure 25 shows the speed-flow comparison matrix presenting all of the data that was collected for all mainline volume scenarios at the on-ramp data collection point (On.Ramp).

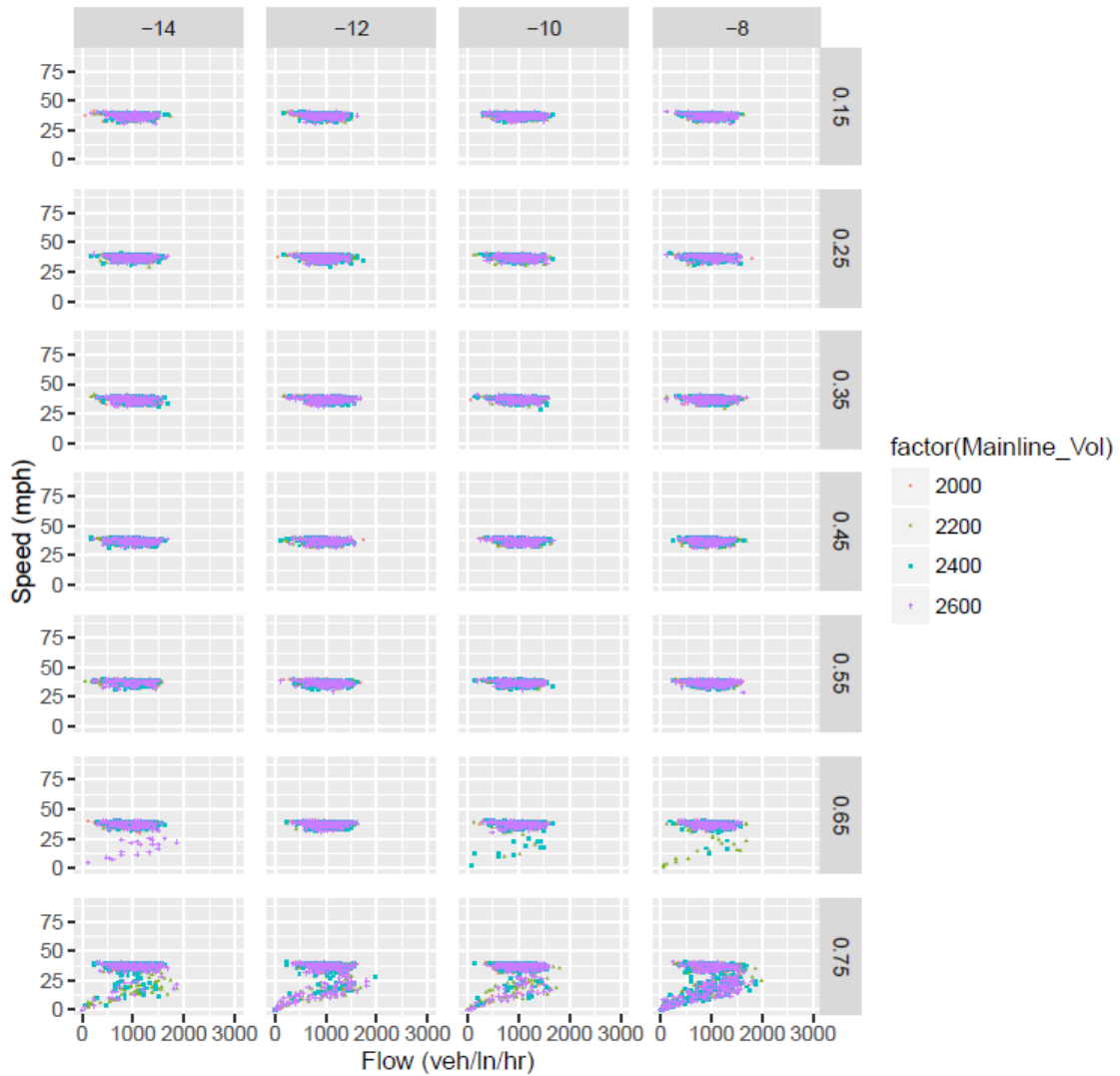


Figure 25: Speed-Flow Comparison Matrix for All Volumes at the On.Ramp with Varying Safety Factors and Coop. Braking (On-Ramp: 1,000vehs)

By adjusting the safety reduction factor to a lower than default value (0.6), there are no data points being collected that show a failure on the on-ramp. However, the

higher safety reduction factors result in significant ramp failure and the ramp no longer processes the full demand. As for the cooperative braking parameter, it can now be seen that when the safety factor is at 0.75 that having a cooperative braking value of -14 ft/sec^2 reduces the amount of congestion seen at higher mainline volumes compared to the data when the cooperative braking is at -8 ft/sec^2 .

4.3 Analysis of the Incremental Desired Speed Algorithm

The Incremental Desired Speed (IDS) algorithm was tested using three threshold values of 10mph, 20mph, and 30mph, each simulated with three speed increment values of 10mph, 15mph and 20mph. The VISSIM default values for the safety reduction factor and cooperative braking parameter were used. Figure 26 is the speed-flow curve for all the mainline volumes at the RL.Merge without IDS.

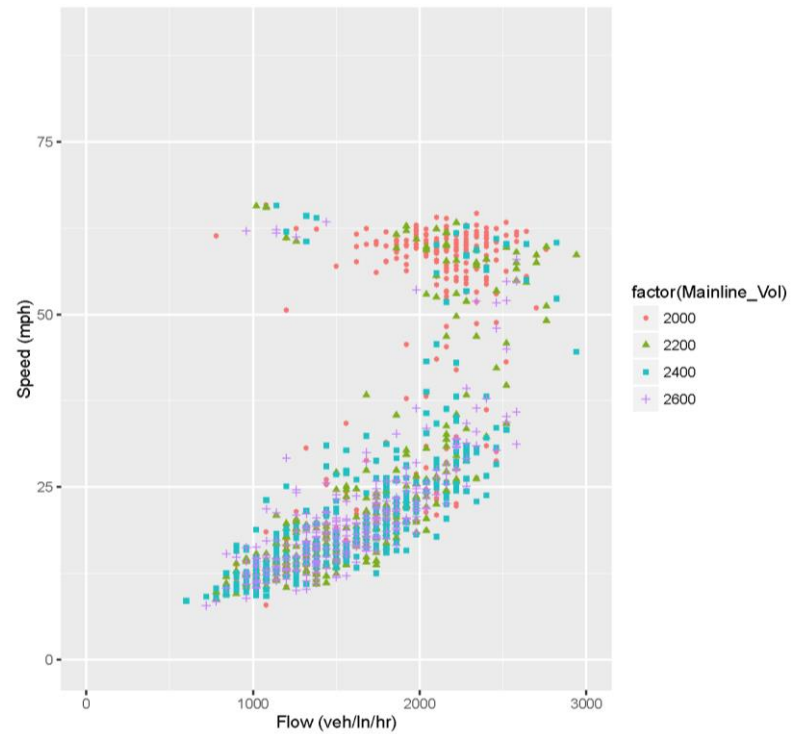


Figure 26: Speed-Flow Curve for All Volumes at the RL.Merge with Default Safety Reduction Factor and Cooperative Braking (On-Ramp: 1,000vehs)

Figure 27 is the speed-flow comparison matrix for all the data collected at the RL.Merge data location point for all traffic volumes using the IDS algorithm and the default safety reduction factor and default cooperative braking. In Figure 27 threshold values are across the top and speed increments are along the right side.

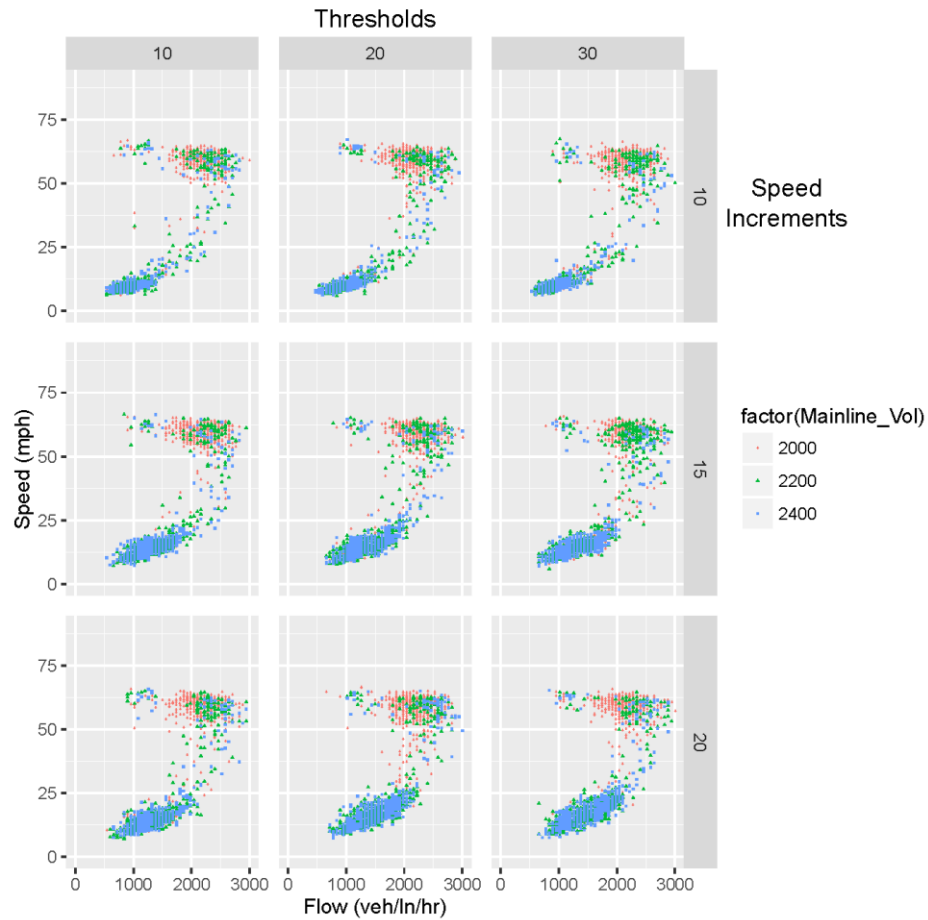


Figure 27: Speed-Flow Comparison Matrix for All Volumes at the RL.Merge with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

From Figure 27 it can be seen that at the 10mph speed increment that all the 2,400veh/ln data points are tightly grouped at the bottom of the curve which is different from the spread out grouping seen in Figure 26. As the speed increment is increased the 2,400veh/ln data spreads out more along the bottom half of the speed-flow curve which is more similar to the default simulation without the IDS algorithm.

Additionally, Figures 28-30 show each mainline volume plotted independently within its own speed-flow comparison matrix for the RL.Merge data collection point in the order of 2,000veh/l_n, 2,200veh/l_n, and 2,400veh/l_n respectively.

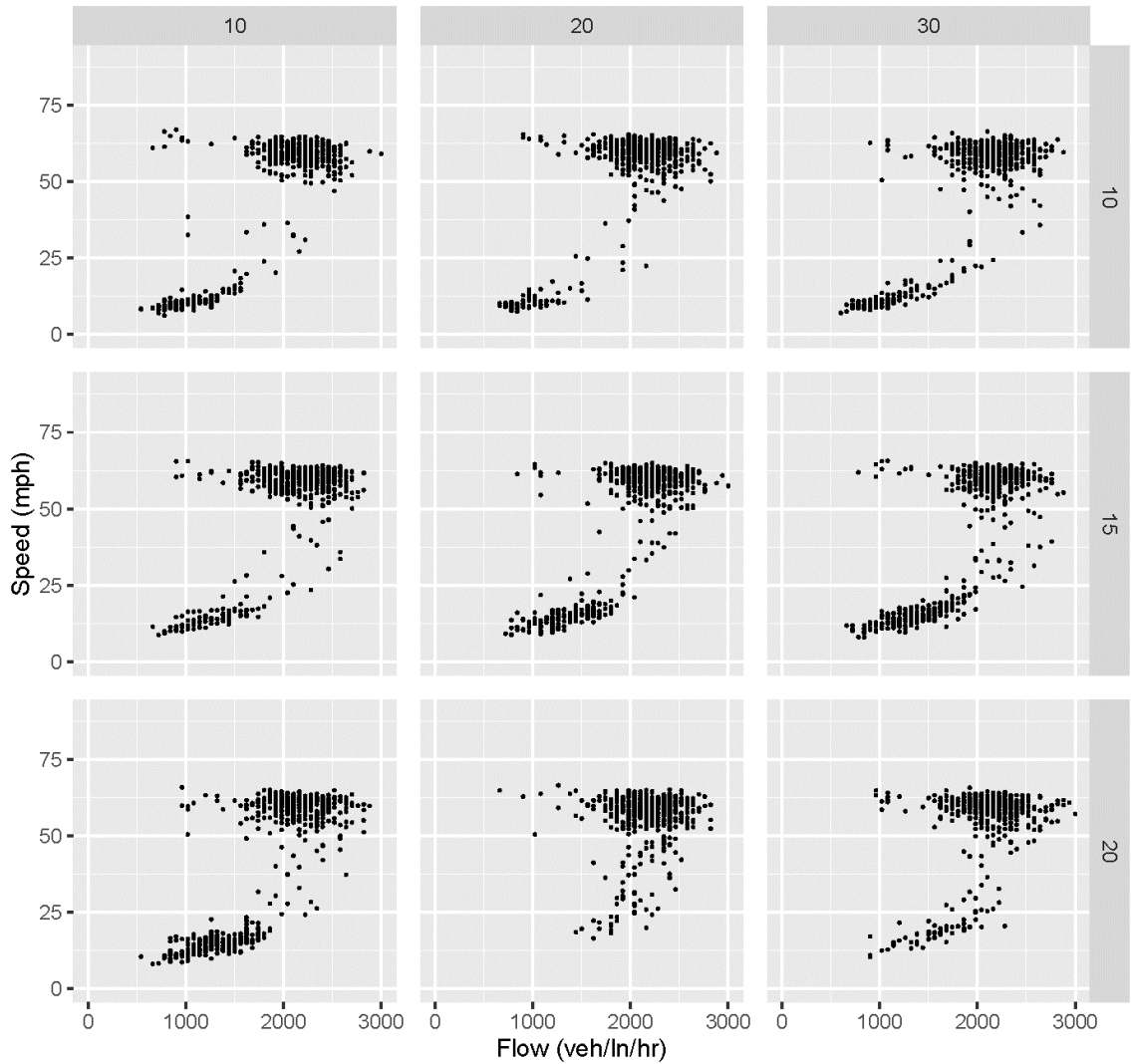


Figure 28: Speed-Flow Comparison Matrix for 2,000veh/l_n at the RL.Merge with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

From Figure 28, which is the 2,000veh/l_n mainline volume results, there is a similar grouping of data points at the bottom of the curve. However, because this data is for a below capacity mainline traffic volume, there should not be large portions of the

data in the lower part of the curve. Furthermore, when the threshold speed was set to 20mph and 30mph with a 20mph speed increment, the results align with the expectations of a below capacity volume simulation speed-flow curve.

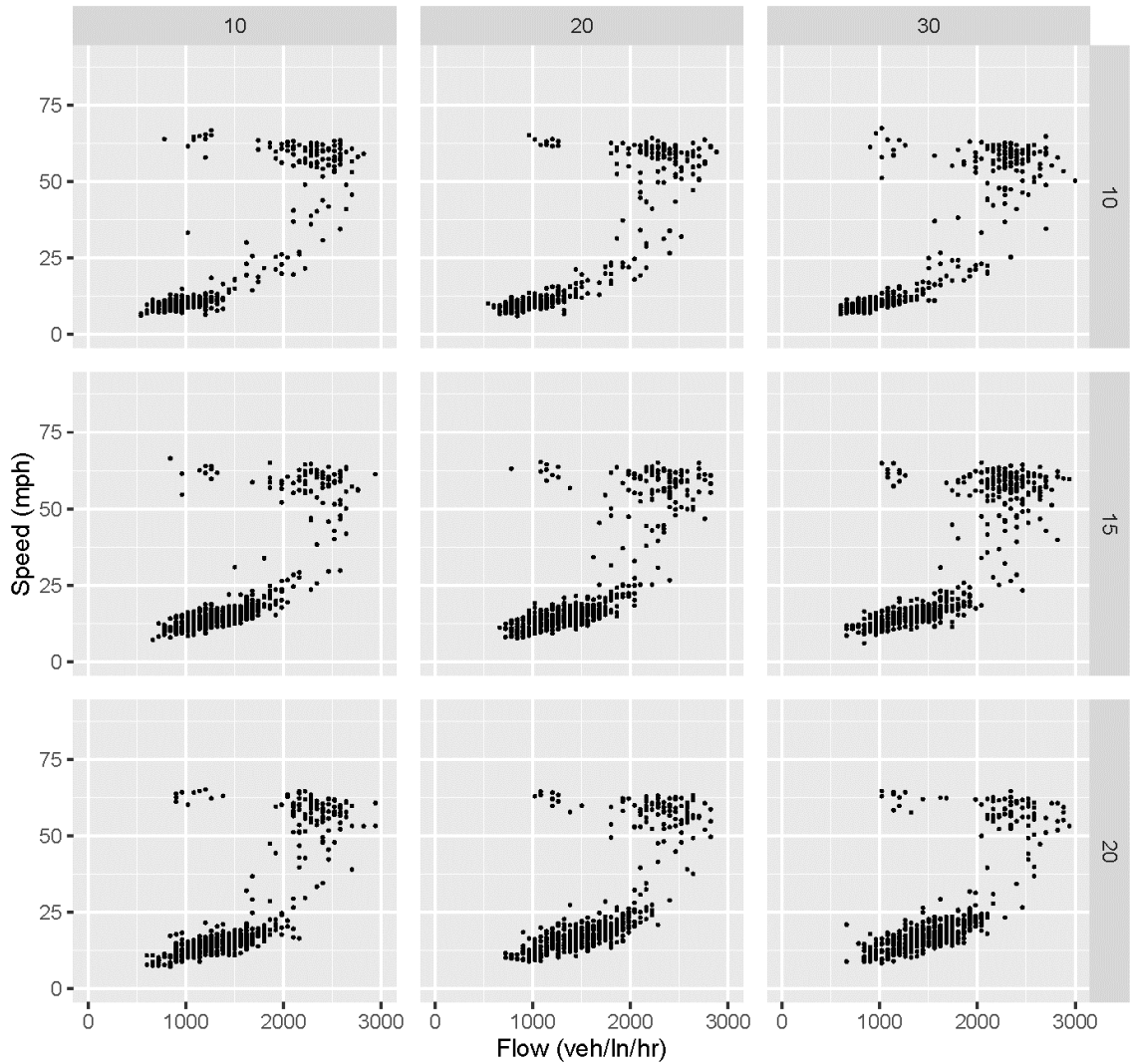


Figure 29: Speed-Flow Comparison Matrix for 2,200veh/ln at the RL.Merge with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

Figure 29 again shows similar results for the 2,200veh/ln mainline volume data with distinct groupings of data points at the bottom of the curve. What is expected to be seen for 2,200 veh/ln volume is a split between where the data appears in the stable and

unstable flows on the speed-flow curve. Knowing that 2,200veh/lh is approximately the capacity of the model and that 2,000veh/lh should produce only slight congestion periodically, the 2,200veh/lh should be in the middle and show a split between stable flow and unstable flow. Figure 26 had a larger portion of the 2,200veh/lh in unstable flow and we can see the IDS algorithm has reduced the overall level of congestion experienced.

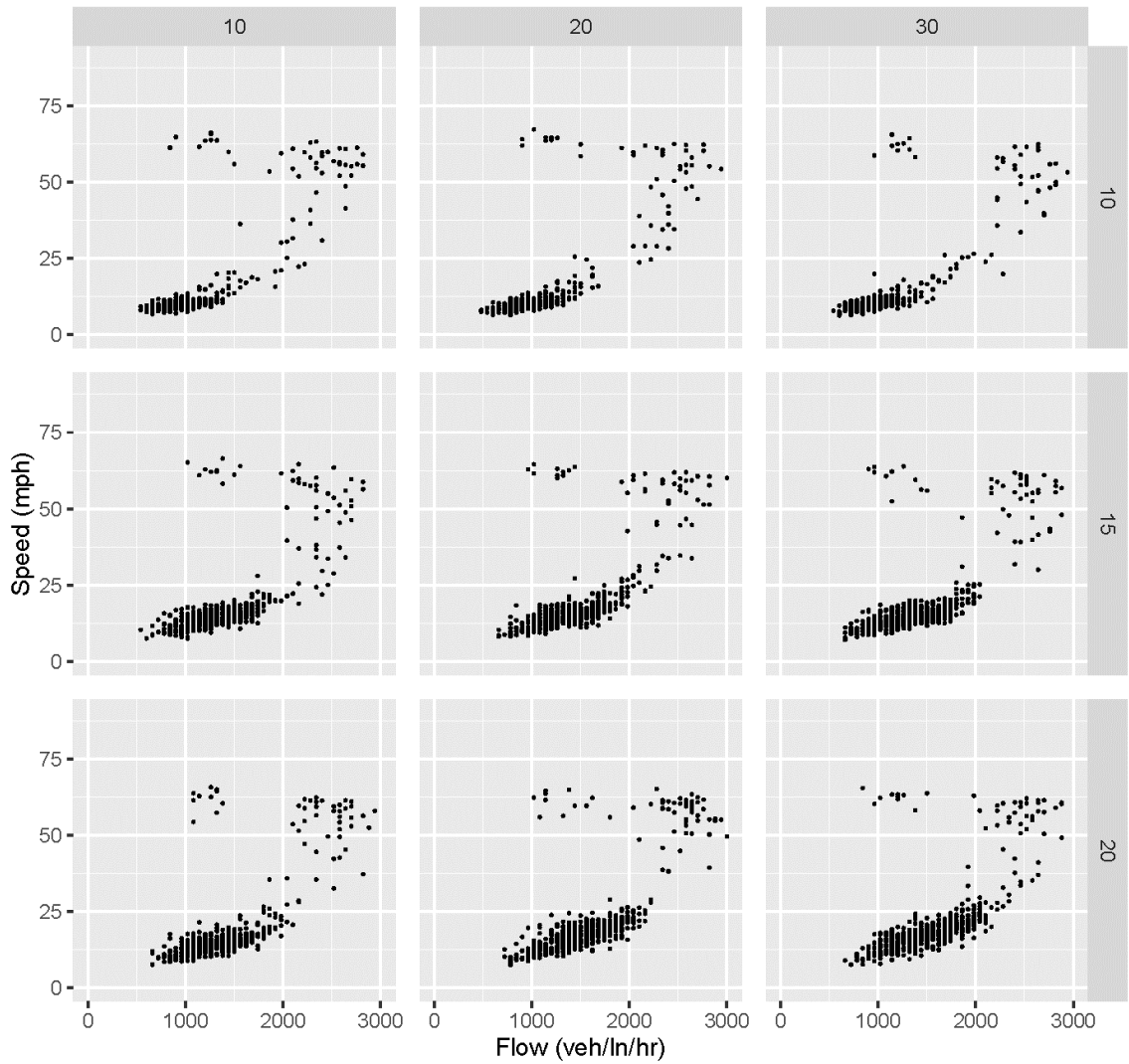


Figure 30: Speed-Flow Comparison Matrix for 2,400veh/lh at the RL.Merge with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

Figure 30 shows that for the 2,400veh/ln data, most of the data is within the unstable flow part of the speed-flow curve. The tight grouping of the data points when the speed increment is set at 10mph implies that the IDS algorithm was likely too restrictive on mainline and introduced unwanted error into the model.

Data collection was also performed on the on-ramp and Figure 31 is the speed-flow comparison matrix for the data collected at the On.Ramp data collection point for all volumes.

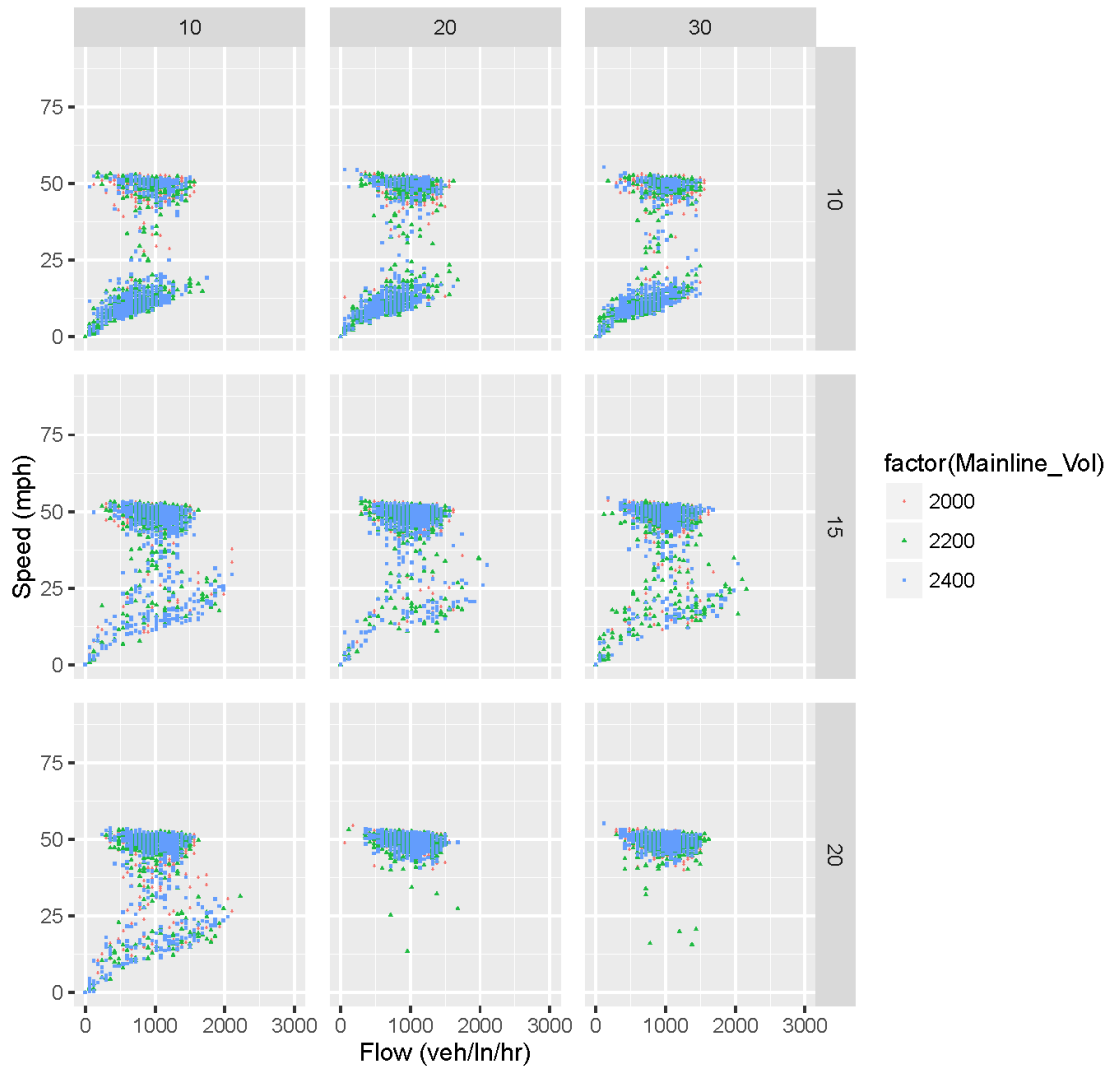


Figure 31: Speed-Flow Comparison Matrix for All Volumes at the On.Ramp with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

From Figure 31 it can be seen that occasionally there were vehicles stopped or traveling at low speeds at the model entrance to the on-ramp; however, a majority of the data points are located at the top of the speed-flow curve around 50mph except for the 10mph speed increment simulations. This limit was likely too restrictive, failing to address the acceleration lane queue until the breakdown was too advanced. There are also two cases where the queue did not reach the model on-ramp entrance point at the higher thresholds with a 20mph speed increment. This implies that the IDS algorithm was successful at allowing the ramp traffic to merge into the freeway under high volume conditions.

Appendix E contains additional speed-flow comparison matrixes for varying threshold and speed increments for the CL.Merge, LL.Merge, RL.Enter, CL.Enter and LL.Enter data collection points where congestion was present.

4.4 Comparison of Non-Ramp Metered and Ramp Metered Case

Using the IDS simulation with a threshold of 30mph and a speed increment of 15mph, a ramp meter was introduced and a before and after comparison of when the ramp meter was off and then turned on completed. Figure 32 is a comparison of the results between the non-ramp metered case and the ramp metered case from the data collected at the RL.Merge data collection point. The non-ramp metered simulation is the left plot labeled “no” and the ramp metered case is the right plot labeled “yes.”

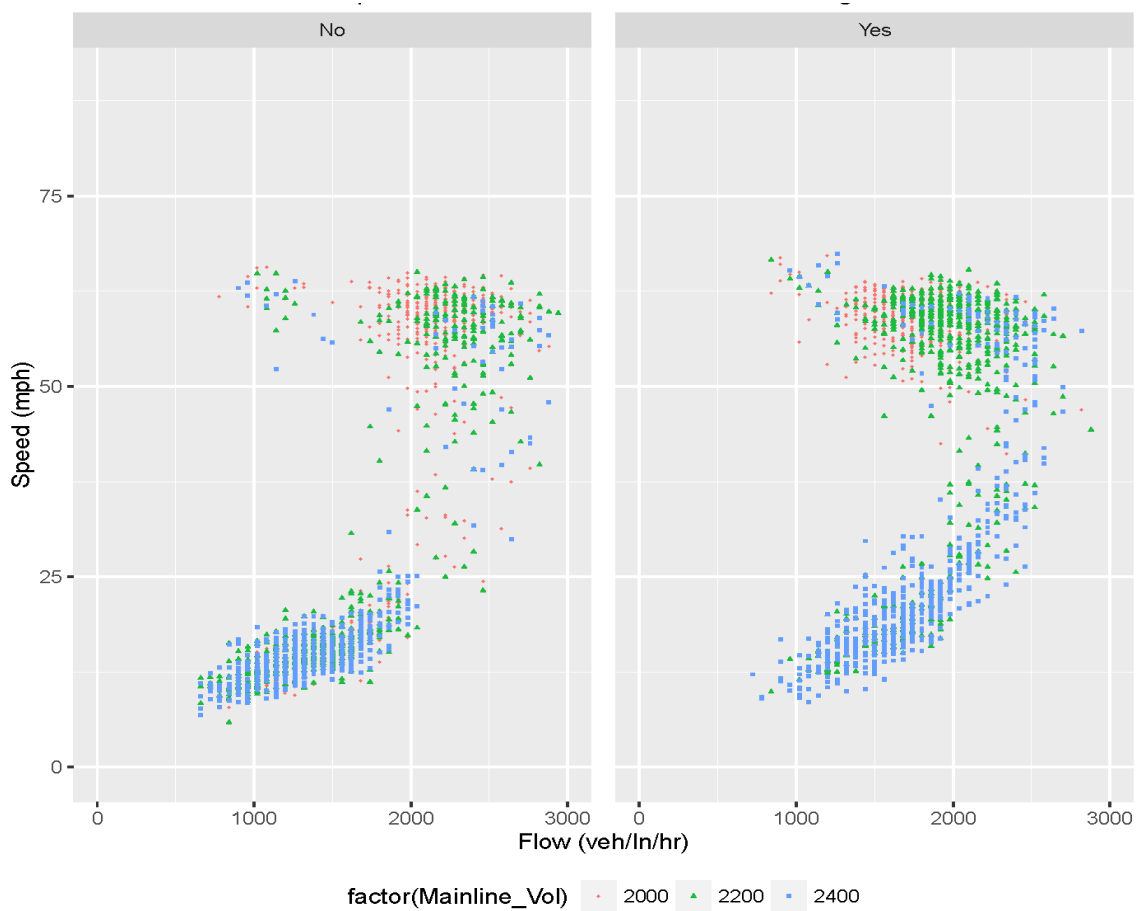


Figure 32: Comparison of Non-Ramp Metered and Ramp Metered Case for All Volumes at the RL.Merge (On-Ramp: 1,000vehs)

From Figure 32 it can be seen that when the ramp meter was turned on that the data points shifted closer to the stable flow half of the speed-flow curve. By plotting each mainline volume individually, a clearer image of the data points shifting upwards can be seen. Figures 33-35 show each mainline volume plotted independently to show the before and after comparison of the implementing a ramp meter for the RL.Merge data collection point in the order of 2,000veh/ln, 2,200veh/ln, and 2,400veh/ln respectively. It is clear that at the 2,000 veh/ln and 2,200 veh/ln (i.e., near and at capacity) mainline volume cases that the ramp meter significantly improved traffic flow.

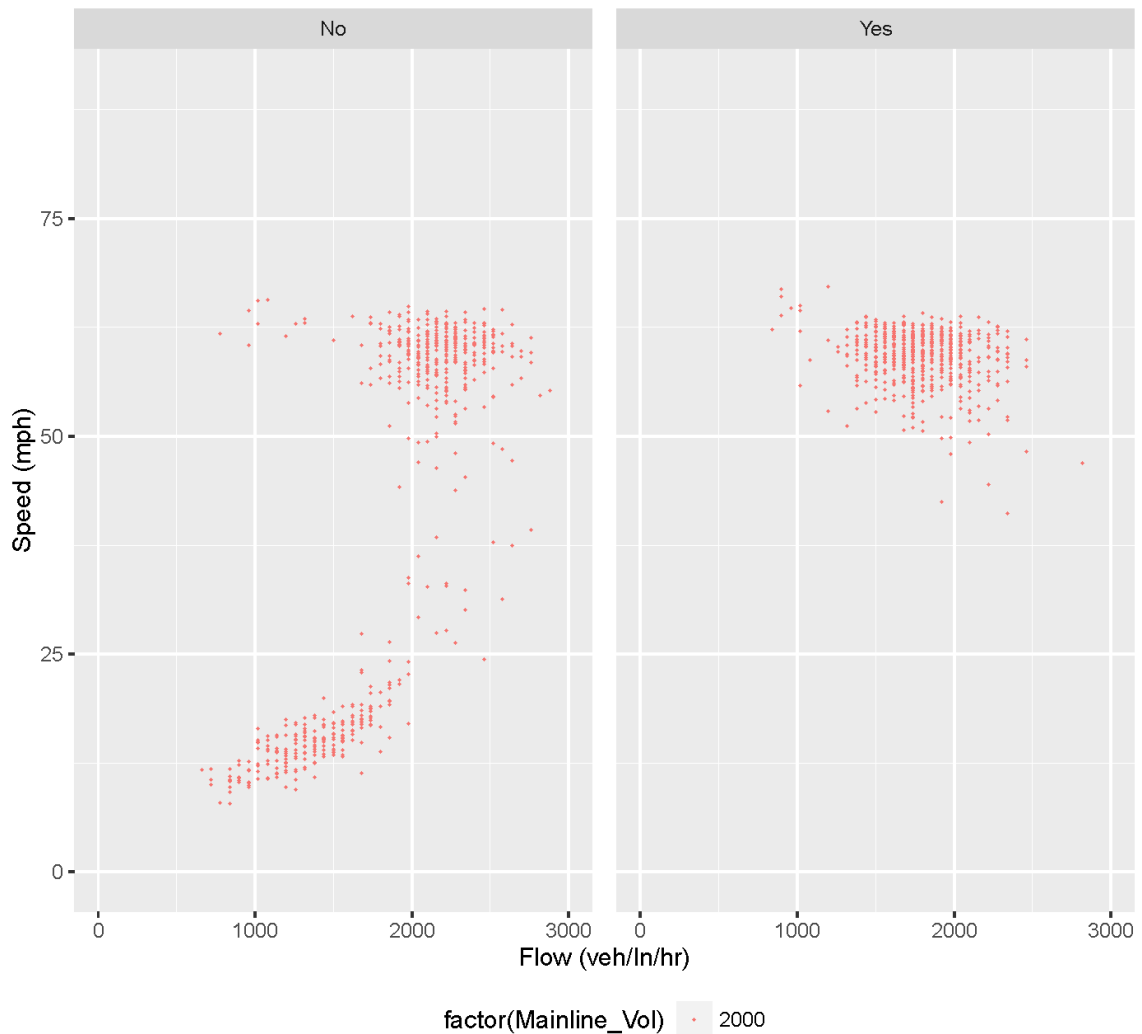


Figure 33: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,000veh/ln at the RL.Merge (On-Ramp: 1,000vehs)

By implementing a ramp meter, all of the data points within Figure 33 moved to the higher part of the speed-flow curve and no longer showed congestion occurring at the 2,000veh/ln mainline volume. Figure 34 which shows the results of the 2,200veh/ln simulations with and without a ramp meter has a similar result where a large portion of the data points moved higher up in the speed-flow curve to a less congested state.

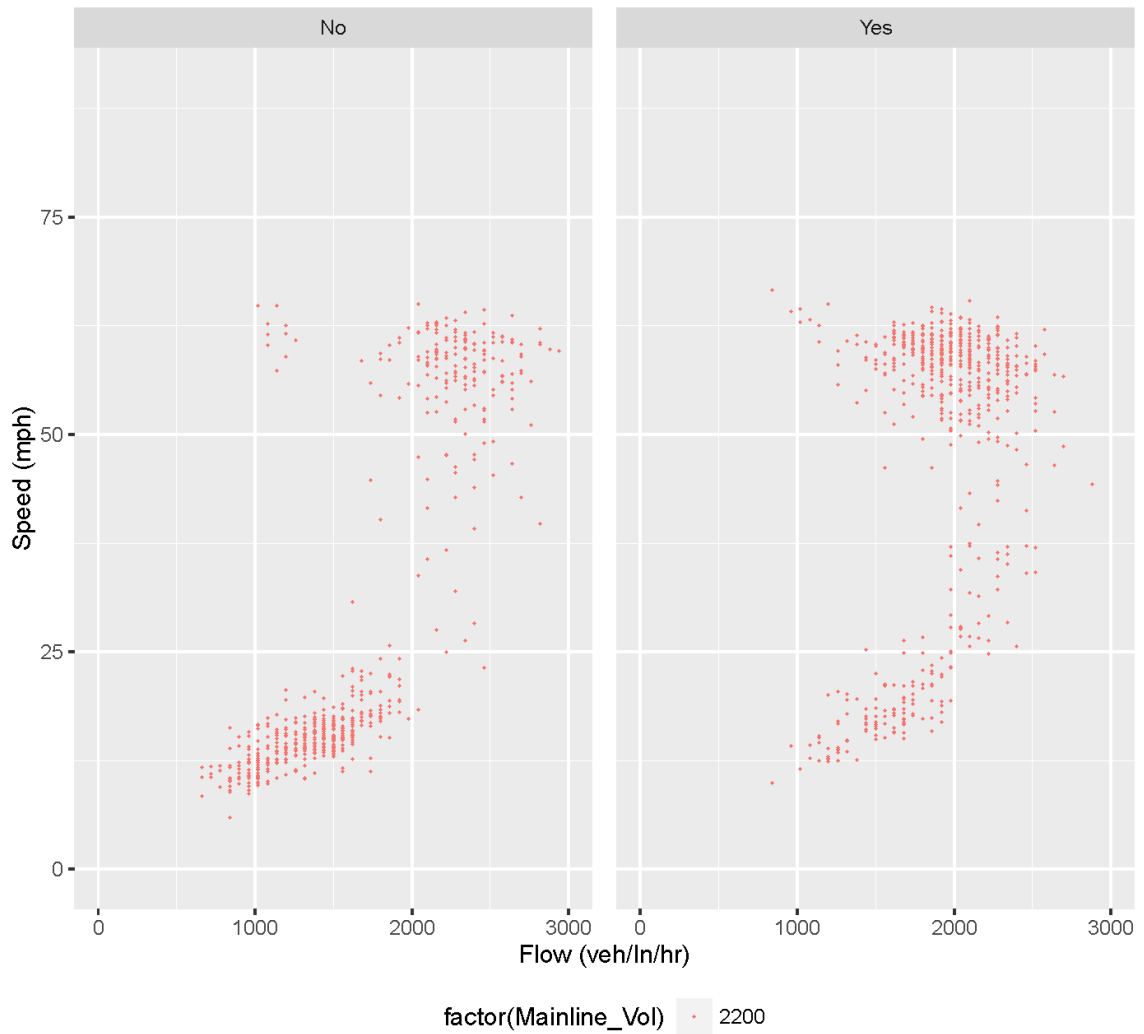


Figure 34: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,200veh/ln at the RL Merge (On-Ramp: 1,000vehs)

Lastly, Figure 35 shows that for 2,400veh/ln implementing a ramp meter increased the flow as well as produced higher speeds even though there was still congestion. More data points may also be found at the top of the speed-flow curve as well.

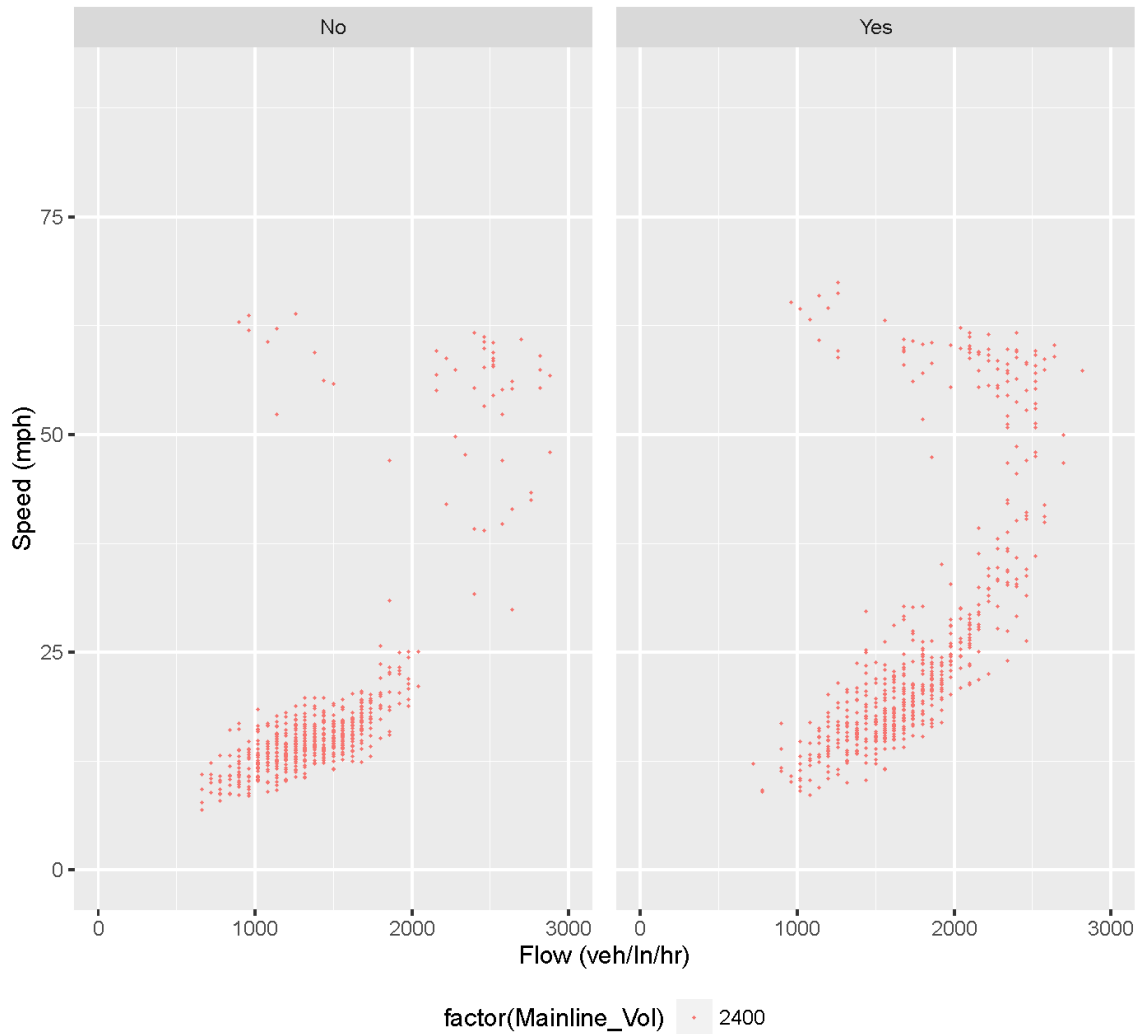


Figure 35: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,400veh/ln at the RL.Merge (On-Ramp: 1,000vehs)

Appendix F contains additional speed-flow comparisons of the non-ramp metered case and the ramp metered case for the CL.Merge, LL.Merge, RL.Enter, CL.Enter and

LL.Enter data collection points for the 30mph threshold and 15mph speed increment IDS algorithm.

To show that the ramp meter has increased the flow of the vehicles being able to enter and exit the model, the total entering and exiting vehicle flows for the non-ramp metered case and the ramp metered case were compared. Also included is the total of vehicles able to pass the ramp meter, allowing for a comparison of the benefits on the mainline with the potential tradeoff of holding cars on the on-ramp. Figure 36 is an example of this comparison of the non-ramp metered case and the ramp metered when the mainline volume was set at 2,200veh/ln at each of the different on-ramp volumes of 600vehs, 800vehs, and 1,000vehs.

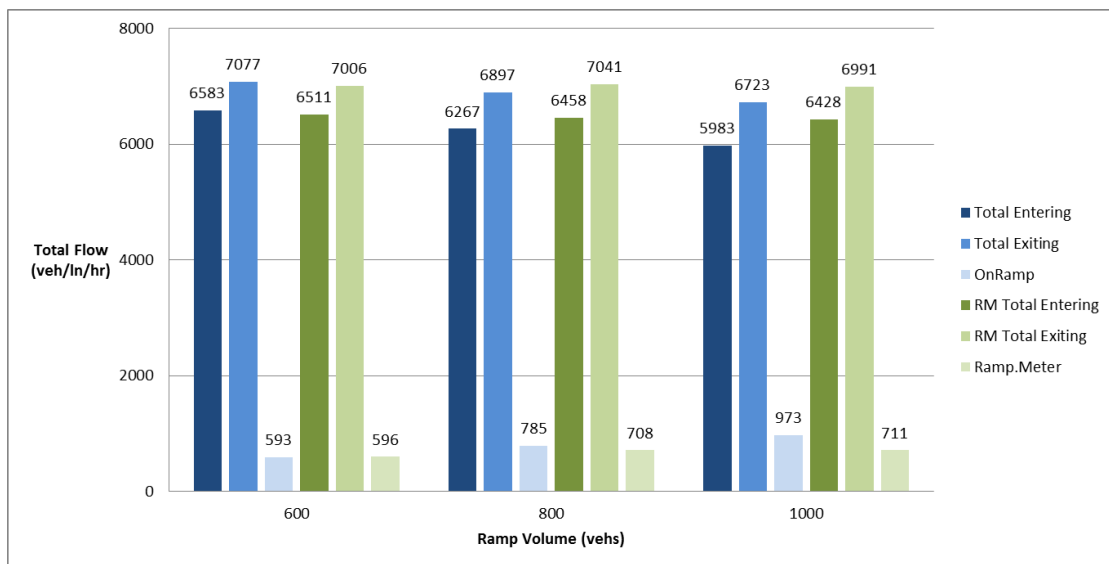


Figure 36: Comparison Bar Plot of Non-Ramp Metered and Ramp Metered Case Total Entering and Exiting Flows for the 2,200veh/ln Mainline Volume

It is seen that the ramp meter with a 3 second user defined delay only allows for a metering rate for around 710veh/hr maximum. Thus for the 800veh and 1,000veh on-ramp volumes 77vehs and 262vehs were held on the on-ramp, respectively, compared to the non-ramp metered case. It is also seen that at the lowest ramp volume of 600vehs that

having the ramp meter has no significant impact on throughput. Figure 37 further shows that for a ramp volume of 600vehs, similar congestion was experienced at the RL.Merge for both the non-ramp metered case and the ramp metered case.

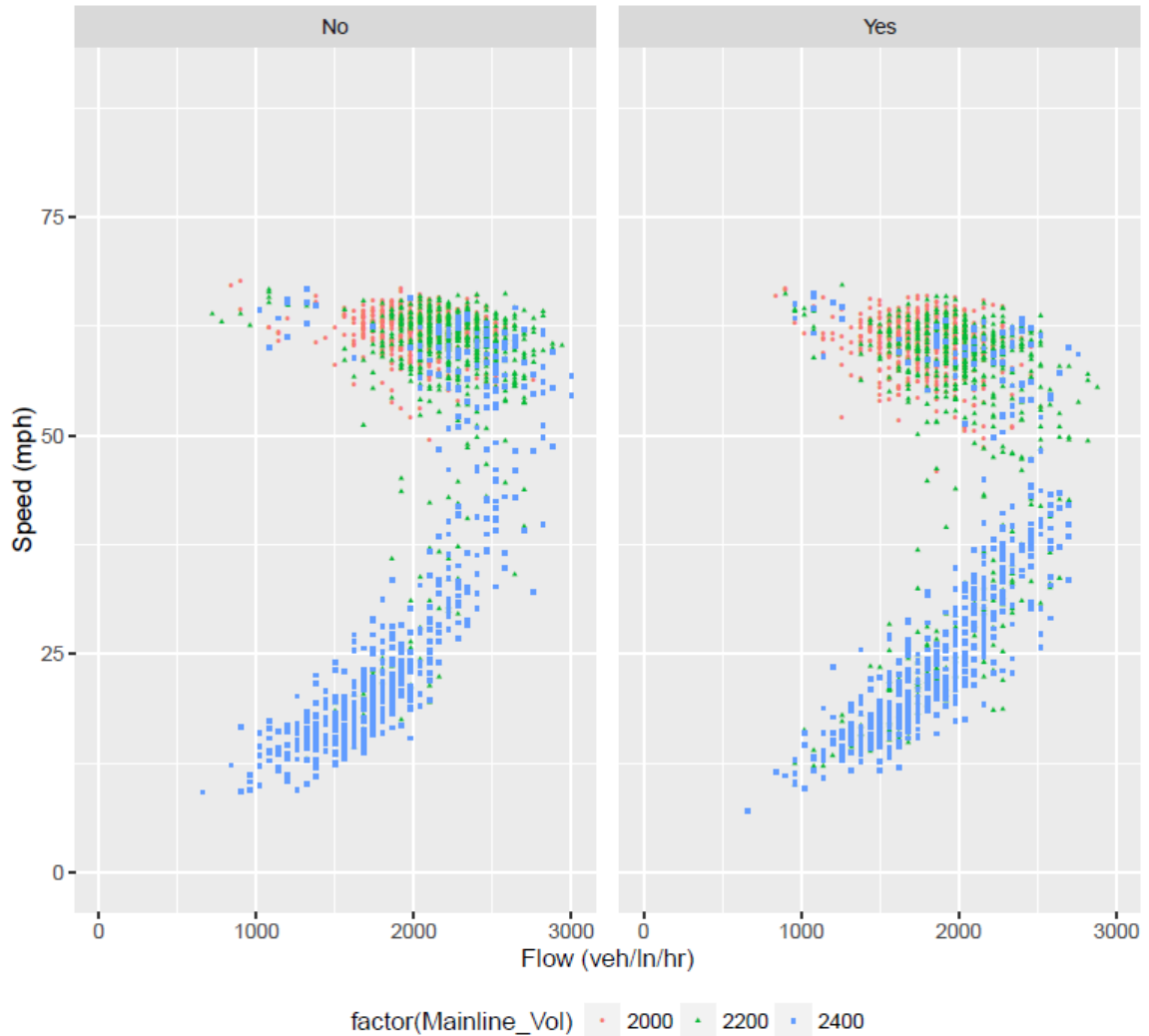


Figure 37: Comparison of Non-Ramp Metered and Ramp Metered Case for All Volumes at the RL.Merge (On-Ramp: 600vehs)

For the 800veh ramp volume there are improvements in the number of vehicles able to enter and exit the system. By holding 77vehs on the ramp and reducing the congestion through metering, the entering flow on the freeway was increased by 191vehs and the exiting flow was increased by 144vehs. Similarly for the 1,000veh ramp volume,

by holding 262vehs on the ramp and reducing the congestion through metering the entering flow was increased by 445vehs and the exiting flow increased by 268vehs. We also recall in Figure 34 that a large increase in the number of vehicles traveling at speeds above 50mph is seen. Thus, the ramp meter greatly improved the travel speeds by smoothing out the vehicle merging process.

Additional comparison bar plots of the entering and exiting flows for the 2,000veh/ln and 2,400veh/ln volumes have been attached in Appendix F.

CHAPTER 5

CONCLUSION AND NEXT STEPS

Having completed all of the analysis and compiled the results, Chapter 5 will further discuss and draw conclusions from each analysis. The discussions will look at the effects of the advance merging and cooperative lane changes, the effects of the safety reduction factor and cooperative braking, the effectiveness of the Incremental Desired Speed algorithm, and lastly the effectiveness of the ramp meter. This thesis will then conclude with discussion of next steps for this research.

5.1 Effects of Advanced Merging and Cooperative Lane Change

Turning on both the advanced merging and cooperative lane change features within VISSIM appeared to give better results, based on review of the speed-flow diagrams, than the default simulation or the simulations where only one or the other setting was turned on. With the default settings, the speed-flow curve was similar to an expected speed-flow curve; however, the unstable flow did not seem to be well reflected. Although, maybe more importantly, when considering the on-ramp data, the default settings created an unrealistic behavior where the queue on the acceleration lane would grow significantly while the freeway mainline operated at free flow speeds. The number of diffusions and remaining vehicles also indicated a large queue formation on the acceleration lane and the on-ramp.

By turning on the advanced merging, there were limited improvements to the speed-flow curve, number of diffusions, and the number of remaining vehicles, and queuing issue. Cooperative lane changing however showed a large improvement in lowering the number of diffusions and the number of remaining vehicles, but the resulting speed-flow curve still did not match the expected curve.

Finally, running the simulation with both advanced merging and cooperative lane changing on produced the speed-flow curve that closely adhered to the shape of the expected speed-flow curve as well as eliminated the long queue that otherwise formed up the on ramp. Furthermore, the number of diffusions dropped substantially as well as the number of remaining cars for the on-ramp dropped to zero across all traffic volumes. Taking into account these results, having both the advanced merging and the cooperative lane change turned on when modeling freeway merging is the first step in reflecting real world merging behavior.

5.2 Effects of the Safety Reduction Factor and Cooperative Braking Parameters

A significant result from the analysis of the safety reduction factor and the cooperative braking parameter was that the safety reduction factor had a stronger influence over the model performance than the cooperative braking parameter. It could be seen at all volumes that as the safety reduction factor was increased, more observations were recorded in the unstable portion of the speed-flow curve. VISSIM's default safety reduction factor of 0.60 would likely not represent the traffic in Atlanta as driver's are likely more aggressive, justifying a lower safety reduction factor. However, this intuition needs to be verified against field data.

The cooperative braking however showed little change in how it affected the model. A range from -14 ft/sec^2 to -8 ft/sec^2 was modeled, which included the default setting of -10 ft/sec^2 . There was minimal observable difference in the mainline freeway speed-flow graphs. However, for the on-ramp it could be seen that for the more aggressive cooperative braking at -14 ft/sec^2 ramp congestion was reduced compared to the less aggressive -8 ft/sec^2 value when the safety reduction factor was 0.65 or higher. The effectiveness of the cooperative braking could be reduced by the fact the cooperative lane change was turned on, which meant vehicles were probably more likely to move over into another lane rather than slowing to allow a vehicle to merge in front. If a two-

lane on-ramp that merged into a single lane acceleration lane was modeled, thus cooperative lane change is not an option, then it may be possible that the cooperative braking parameter would have a greater effect. Another consideration when adjusting the cooperative braking parameter to a more aggressive value is that the effect of having the mainline vehicles braking harder to allow merging vehicles to change lanes could increase the likelihood of breakdown on the mainline.

Overall, this analysis showed the effects that the safety reduction factor and cooperative braking parameters have on the simulation results. To effectively choose values for a simulation model, it would be best to have the speed-flow curves of the real world data for calibration.

5.3 Effectiveness of the Incremental Desired Speed Algorithm

The purpose of developing the Incremental Desired Speed (IDS) algorithm was to minimize the speed differential between vehicles on the mainline and the vehicles on the acceleration lane when a queue is beginning to build. It has been shown in previous efforts that real world drivers are hesitant to drive at free flow speeds past an adjacent line of stopped vehicles that are needing to merge into their lane [24]. The likelihood of a stopped or slowed vehicle forcing a merge will reduce the acceptable speed of the drivers in the potential merge lane. VISSIM currently does not have a feature or setting to reflect this behavior. Using COM to manipulate VISSIM objects it is possible to adjust the desired speeds of the mainline incrementally, lane-by-lane, based on the average speed being calculated on the acceleration lane.

Using threshold values of 10mph, 20mph, and 30mph with speed increments of 10mph, 15mph, and 20mph, we saw that vehicles on the acceleration lane had an improved likelihood of merging onto the mainline. It was also seen that when performing the simulation at the default safety reduction factor and cooperative braking parameter without the IDS algorithm (Figure 24) that there was a large portion of the 2,200veh/ln

data in the unstable flow. When the IDS algorithm was introduced to improve the merging behavior, the 2,200veh/ln experienced more stable flow in the speed-flow diagram.

Another observation when using the IDS algorithm was that the lowest speed increment of 10mph was too restrictive to the mainline, resulting in increased unstable flow. This shows that the IDS algorithm could add additional unwanted error into the model and must be calibrated to field data. For this study the best results appeared to be at a threshold of 20mph or 30mph with a speed increment of 15mph or 20mph. Having real world data to compare to would provide the needed information to choose the correct threshold and speed increment.

5.4 Effectiveness of Ramp Meter

By implementing a ramp meter in the model we were able to show an increase in the total traffic flows and speeds for all traffic volumes. When looking at the data from the RL.Merge data collection point, each individual mainline volume plot showed less congestion for the ramp metered case than the non-ramp metered case. At the lowest mainline volume of 2,000veh/ln, data points shifted upwards to speeds over 50mph. Furthermore, the number of data points for the 2,200veh/ln scenario also showed less congestion and more data points with speeds above 50mph. As for the 2,400veh/ln scenario mainline volume plot, there was not a tightly grouped collection of data points at the bottom of the speed-flow curve as seen in the non-ramp metered case.

It was also important to see how the ramp meter changed the total flow values entering and exiting the model at the cost of restricting cars from merging onto the mainline. For low ramp volumes of 600 vehicles there was not an improvement in the total flows or the overall speeds recorded. However, when the on ramp volumes were increased there were increases in both total flows and the overall speeds.

5.5 Next Steps

The next step for this research is to obtain traffic data from Georgia freeways to calibrate the safety reduction factor, cooperative braking parameter, and IDS settings. Then, by applying lessons from these analyses, a VISSIM model of a freeway network can be created to test and develop a system wide ramp metering control strategy for Georgia. By having the real world data, speed-flow curves can be created and then compared to the speed-flow comparison matrices presented in this thesis.

There will be the need to study the IDS algorithm more to see how having larger speed increments or thresholds affect the data. Furthermore, because we do not want to add error into the model from the IDS algorithm, a larger range of settings should be studied. Suggestions would include looking at thresholds of 20mph, 30mph, and 40mph with varying speed increments of 15mph, 20mph, 25mph, and 30mph. Having the real world data will again help calibrate these parameters.

In conclusion, this thesis has created a basic understanding of how specific changes to the VISSIM vehicle driver behavior will change the outcome of a freeway on ramp simulation. This will allow further research to continue forward with the development of a VISSIM freeway model and the development of a system wide ramp metering control strategy for Georgia.

APPENDIX A

VISSIM COM SIMULATION CODE

```

1 Imports System.Text
2 Imports System.Convert
3 Imports System.Math
4 Imports System
5 Imports System.IO
6 Imports System.Threading
7
8 Imports VISSIM_COMSERVERLib
9
10 Module Module1
11
12     Sub Main()
13
14         Dim vissim As Vissim
15         Dim simulation As Simulation
16         Dim decision As RoutingDecision
17         Dim evaluation As Evaluation
18
19         Dim vehicles As Vehicles
20         Dim vehicle As Vehicle
21         Dim links As Links
22         Dim link As Link
23         Dim net As Net
24
25
26         For vol = 6000 To 7200 Step 600 '6000 7800
27             For rampvol = 600 To 1000 Step 200 '600 1000
28                 Dim dict As New HashSet(Of Integer)
29                 For i = 1 To 10 Step 1 '5
30                     Randomize()
31                     Dim rndseed As Integer = CInt(Rnd() * 998) + 1
32                     While (dict.Contains(rndseed))
33                         rndseed = CInt(Rnd() * 998) + 1
34                     End While
35                     dict.Add(rndseed)
36                     vissim = CreateObject("vissim.VISSIM.540")
37
38                     'FILE PATH NAME
39                     vissim.LoadNet("C:\Users\mwhaley6\Documents\Tyler Whaley\Vissim
Models\Vissim 5.4 files\On Ramp.inp")
40
41                     vissim.ShowMinimized() 'Minimize the window
42                     vissim.Graphics.AttValue("visualization") = 0 'Not showing the
individual vehicles
43
44                     simulation = vissim.Simulation
45                     simulation.RandomSeed = rndseed
46                     evaluation = vissim.Evaluation
47                     evaluation.AttValue("datacollection") = True
48                     evaluation.AttValue("queuelength") = True
49
50
51                     Dim vehinput As VehicleInput
52
53                     'Mainline
54                     vehinput = vissim.Net.VehicleInputs.GetVehicleInputByNumber(1)
55                     vehinput.AttValue("volume") = vol
56
57                     'On-ramp
58                     vehinput = vissim.Net.VehicleInputs.GetVehicleInputByNumber(2)
59
60
61
62

```

Figure 38: VISSIM COM Simulation Code Part 1

```

63
64 'Incremental Desired Speed Code (Refer to Chapter 3 Section 3.4)
65 '#####
66 Dim ii As Integer
67 Dim SimulationTime As Single
68 Dim RampSpeed As Integer 'Averge vehicle speed over checked range
69 Dim RampSpeedi As Integer 'Speed of ith ramp vehicle within checked range on
    acceleration range
70 Dim RampSpeedc As Integer 'Cumulative total of Rampspeedi vehicles
71 Dim RampCount As Integer 'number of ramp vehicle in checked range
72
73 For ii = 1 To 18000
74     simulation.RunSingleStep()
75     SimulationTime = simulation.AttValue("elapsedtime")
76
77     If SimulationTime Mod 5 = 0 Then
78
79         For Each vehicle In vissim.Net.Links.GetLinkByNumber(6).GetVehicles
80             RampSpeed = vehicle.AttValue("speed")
81         Next
82
83         RampSpeed = 50
84         RampCount = 0
85         RampSpeedc = 0
86         RampSpeedi = 0
87
88         For Each vehicle In vissim.Net.Links.GetLinkByNumber(5).GetVehicles
89             If vehicle.AttValue("lane") = 1 And vehicle.AttValue("linkcoord") > 750
                Then
90                 RampSpeedi = vehicle.AttValue("speed")
91                 RampSpeedc = RampSpeedc + RampSpeedi
92                 RampCount = RampCount + 1
93                 If RampCount > 3 Then
94                     RampSpeed = RampSpeedc / RampCount
95                 Else
96                     RampSpeed = 50
97                 End If
98             End If
99         Next
100
101         For Each vehicle In vissim.Net.Links.GetLinkByNumber(5).GetVehicles
102             If RampSpeed < 30 Then
103
104                 If vehicle.AttValue("lane") = 2 Then
105                     vehicle.AttValue("desiredspeed") = RampSpeed + 15
106                     'vehicle.AttValue("color") = RGB(255, 0, 0)
107
108                 ElseIf vehicle.AttValue("lane") = 3 Then
109                     vehicle.AttValue("desiredspeed") = Min(RampSpeed + 30, 65)
110                     'vehicle.AttValue("color") = RGB(255, 102, 102)
111
112                 ElseIf vehicle.AttValue("lane") = 4 Then
113                     vehicle.AttValue("desiredspeed") = Min(RampSpeed + 45, 65)
114
115                 End If
116             End If
117         Next
118     End If
119 Next
120
121     '#####
122     '#####
123     vissim.Exit()
124
125     Thread.Sleep(2000)
126
127 Next
128 End Sub
129 End Module
130

```

Figure 39: VISSIM COM Simulation Code Part 2

APPENDIX B

VISSIM RAMP METER CODE FILES

1.6.1 VAP File Code

```
PROGRAM RAMPMETER;

SUBROUTINE Ramp_Meter;

Call2:= presence(2) or occupancy(2);
Call4:= presence(4) or occupancy(4);

IF (call4) THEN
    set_sg(1,Red);
    start(ClearanceTimer);
ELSE
    IF ((Call2) and (ClearanceTimer >= 3)) THEN
        set_sg(1,Green);
        stop(ClearanceTimer);
        reset(ClearanceTimer);
    END;
END.

GOSUB Ramp_Meter.
```

1.6.2 PUA File Code

```
$SIGNAL_GROUPS
$
K1 1

$STAGES
$
Stage_1 K1

$STARTING_STAGE
$
Stage_1

$END
```

Figure 40: VISSIM Ramp Meter Code Files [21]

APPENDIX C

ADDITIONAL ADVANCED MERGING AND COOPERATIVE LANE CHANGE SPEED-FLOW COMPARISON MATRICES

The additional speed-flow comparison matrices within Appendix C have been ordered as follows: CL.Merge, LL.Merge, RL.Enter, CL.Enter and LL.Enter.

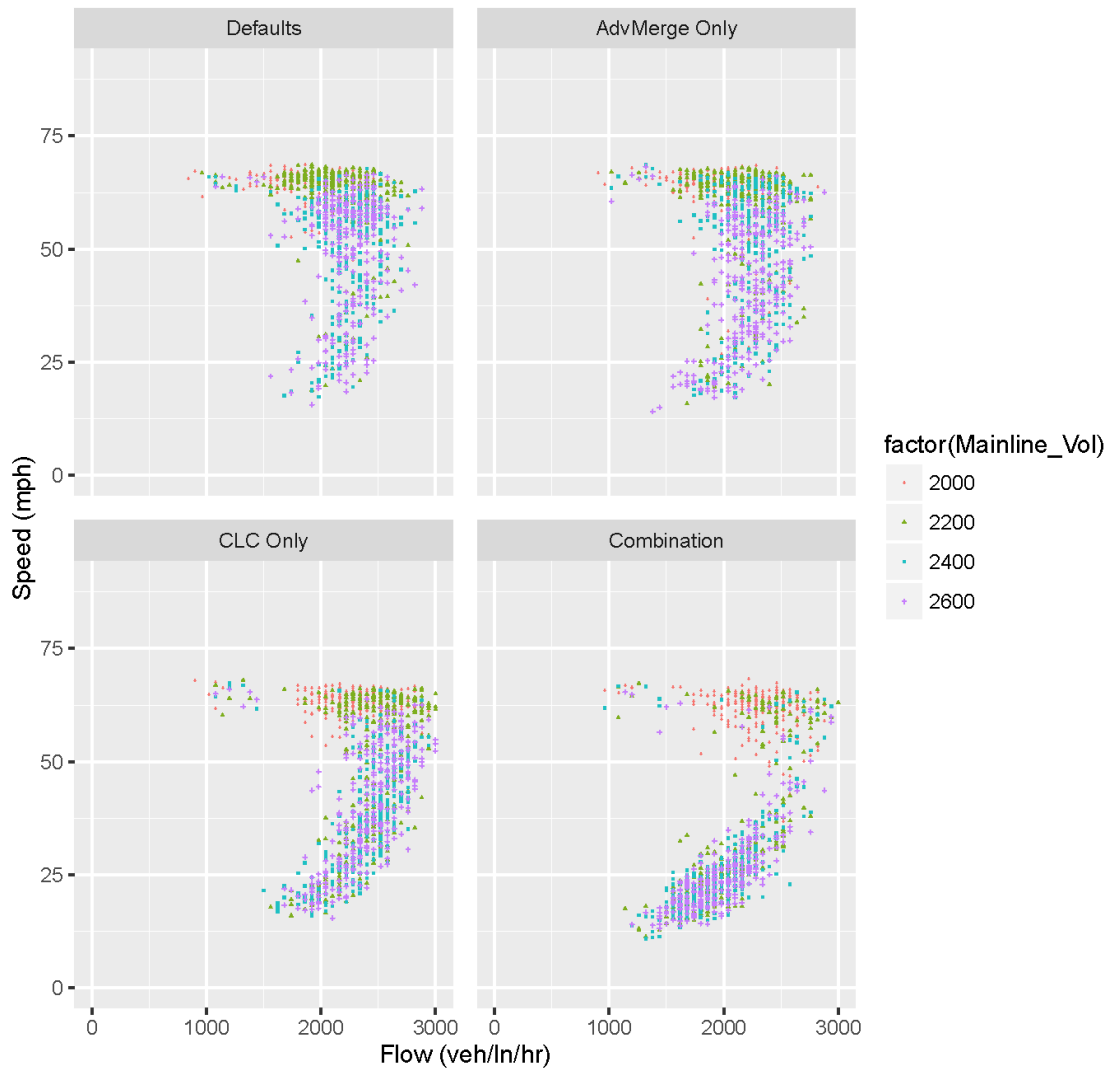


Figure 41: Speed-Flow Comparison Matrix for Varying AdvMerge and CLC Settings at All Mainline Volumes at the CL.Merge (On-Ramp: 1,000vehs)

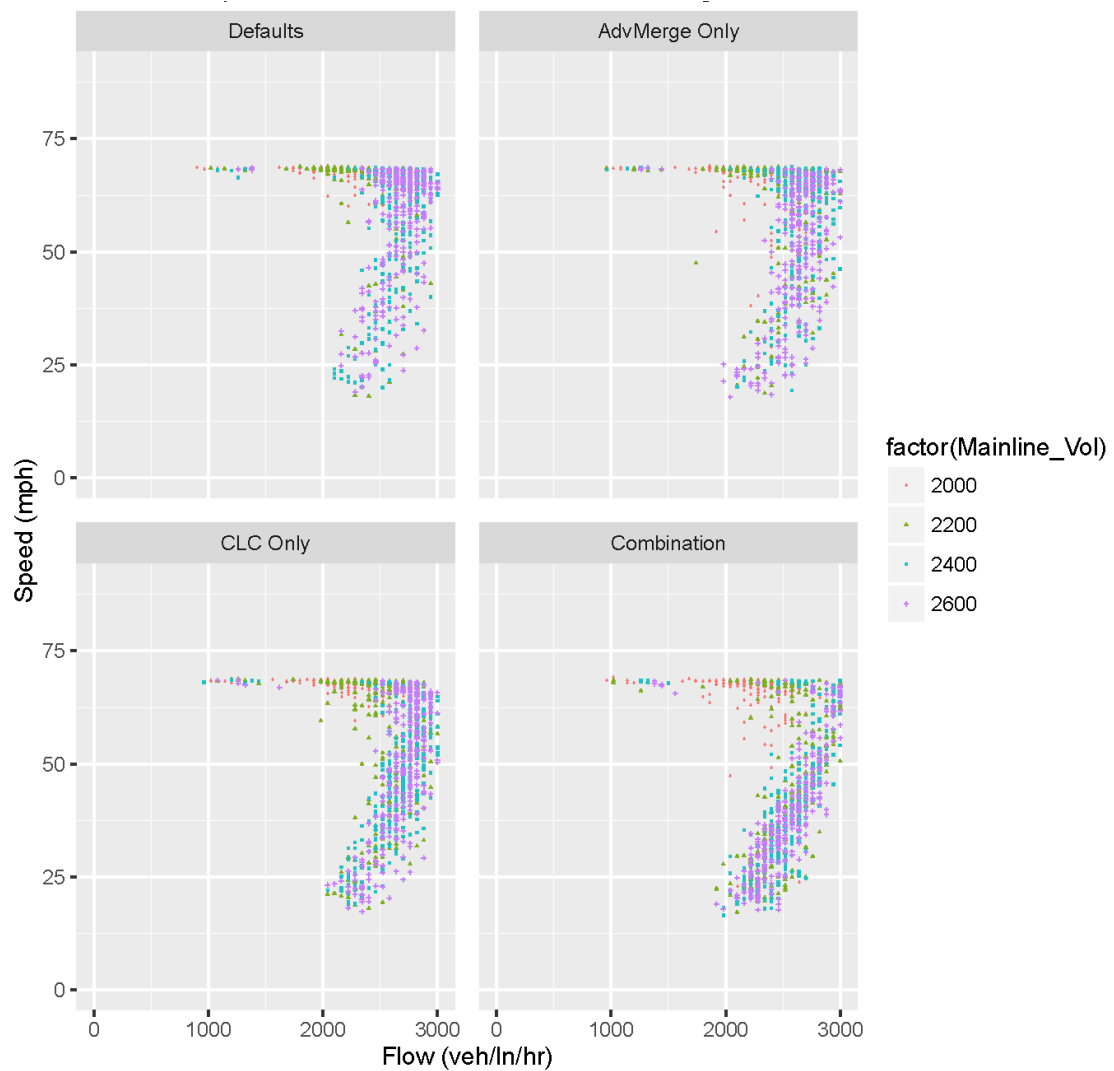


Figure 42: Speed-Flow Comparison Matrix for Varying AdvMerge and CLC Settings at All Mainline Volumes at the LL.Merge (On-Ramp: 1,000vehs)

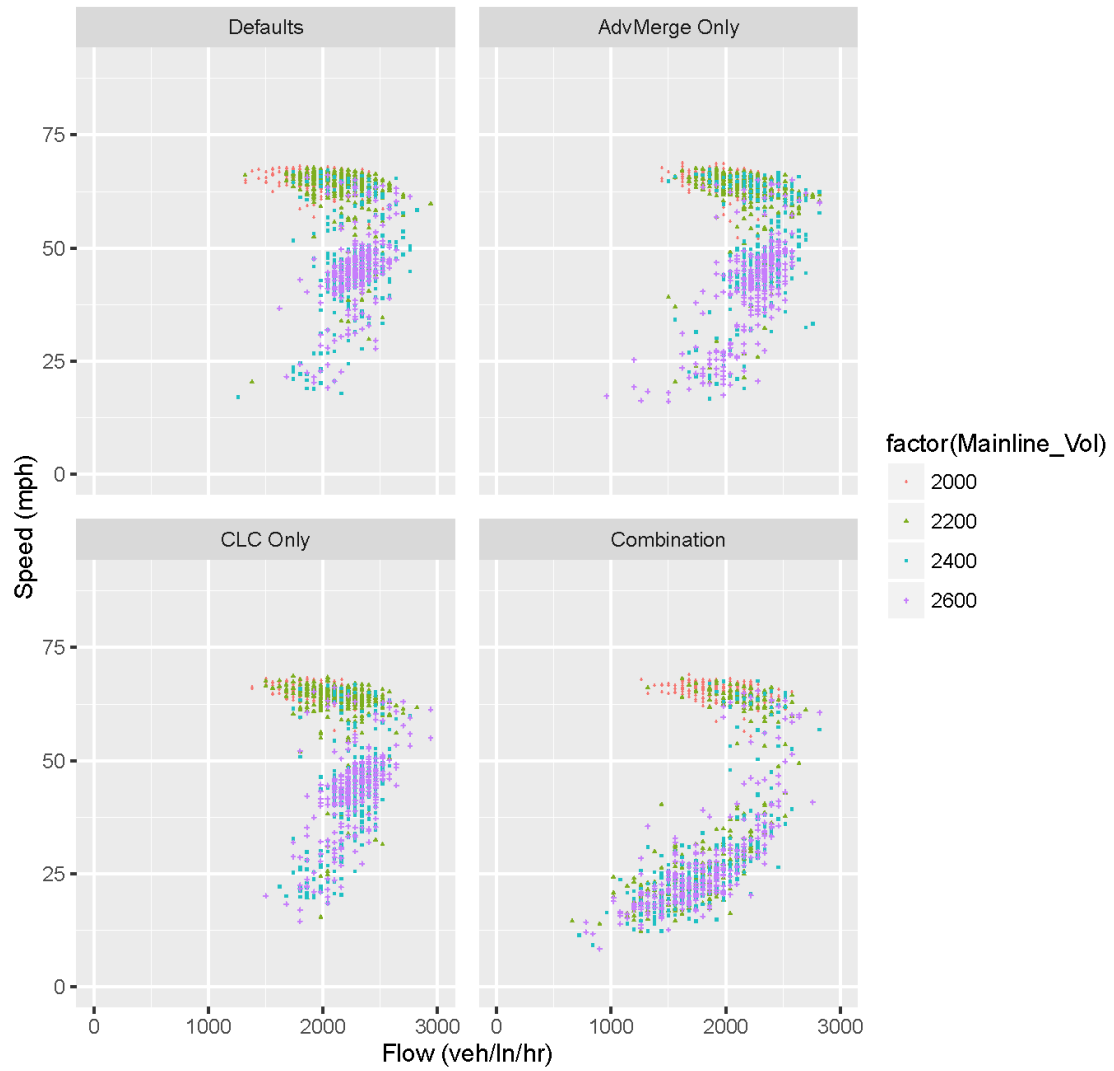


Figure 43: Speed-Flow Comparison Matrix for Varying AdvMerge and CLC Settings at All Mainline Volumes at the RL.Enter (On-Ramp: 1,000vehs)

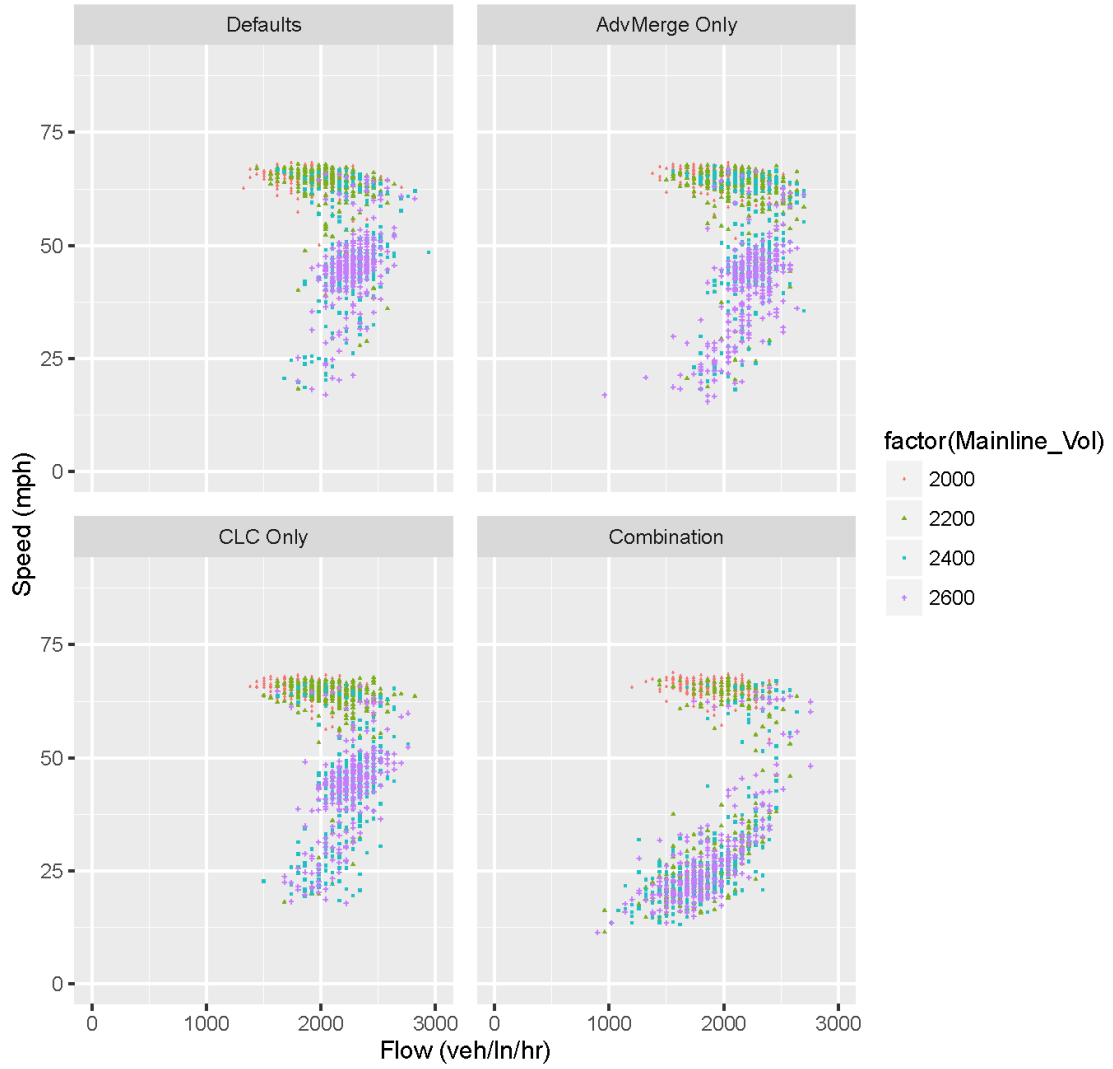


Figure 44: Speed-Flow Comparison Matrix for Varying AdvMerge and CLC Settings at All Mainline Volumes at the CL.Enter (On-Ramp: 1,000vehs)

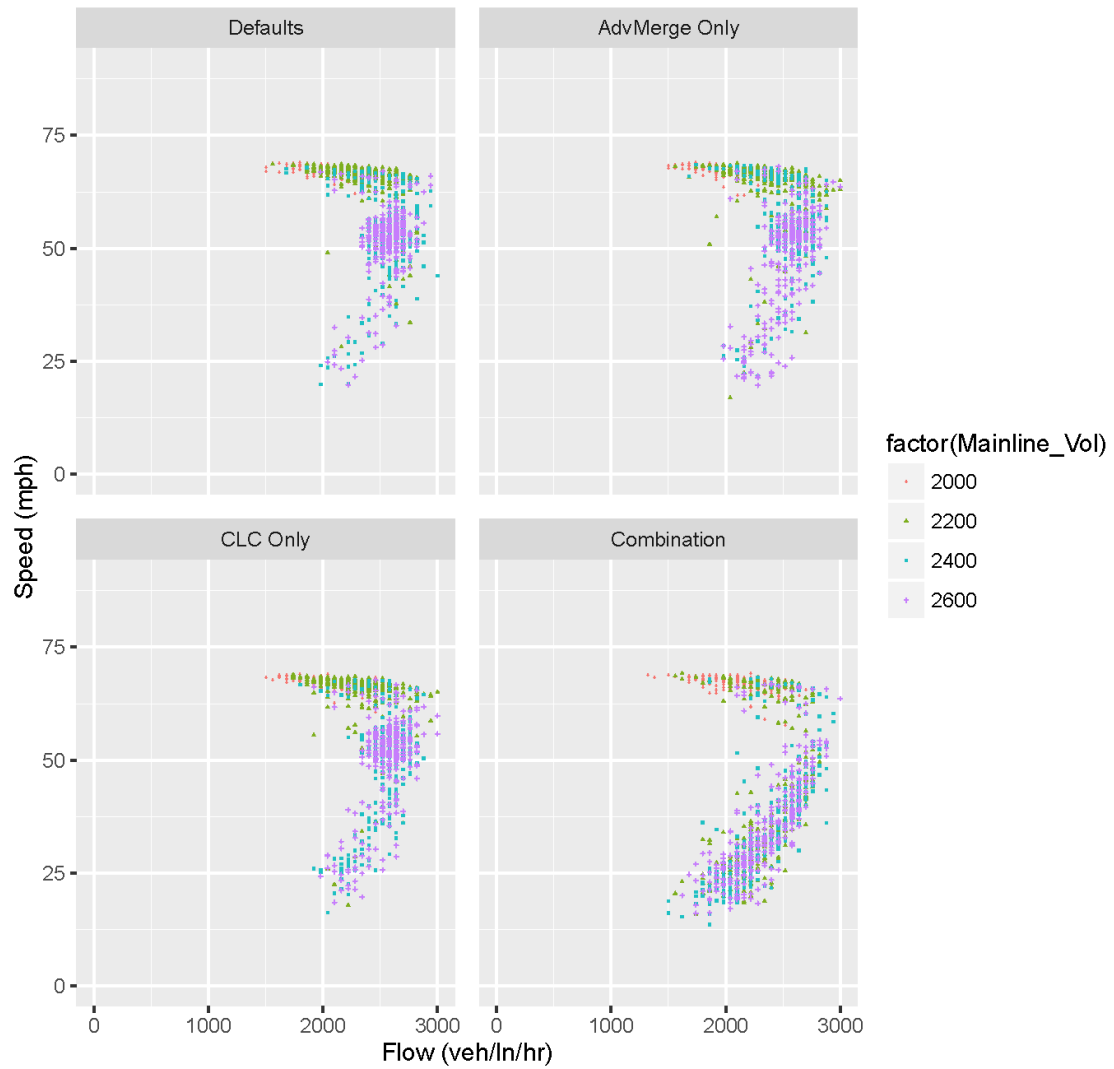


Figure 45: Speed-Flow Comparison Matrix for Varying AdvMerge and CLC Settings at All Mainline Volumes at the LL.Enter (On-Ramp: 1,000vehs)

APPENDIX D

ADDITIONAL SAFETY REDUCTION FACTOR AND

COOPERATIVE BRAKING SPEED-FLOW COMPARISON

MATRICES

The additional speed-flow comparison matrices within Appendix D have been ordered as follows: CL.Merge, LL.Merge, RL.Enter, CL.Enter and LL.Enter. The first figure for each data collection point will be of all the data points plotted followed by four more figures with each mainline volume plotted individually.

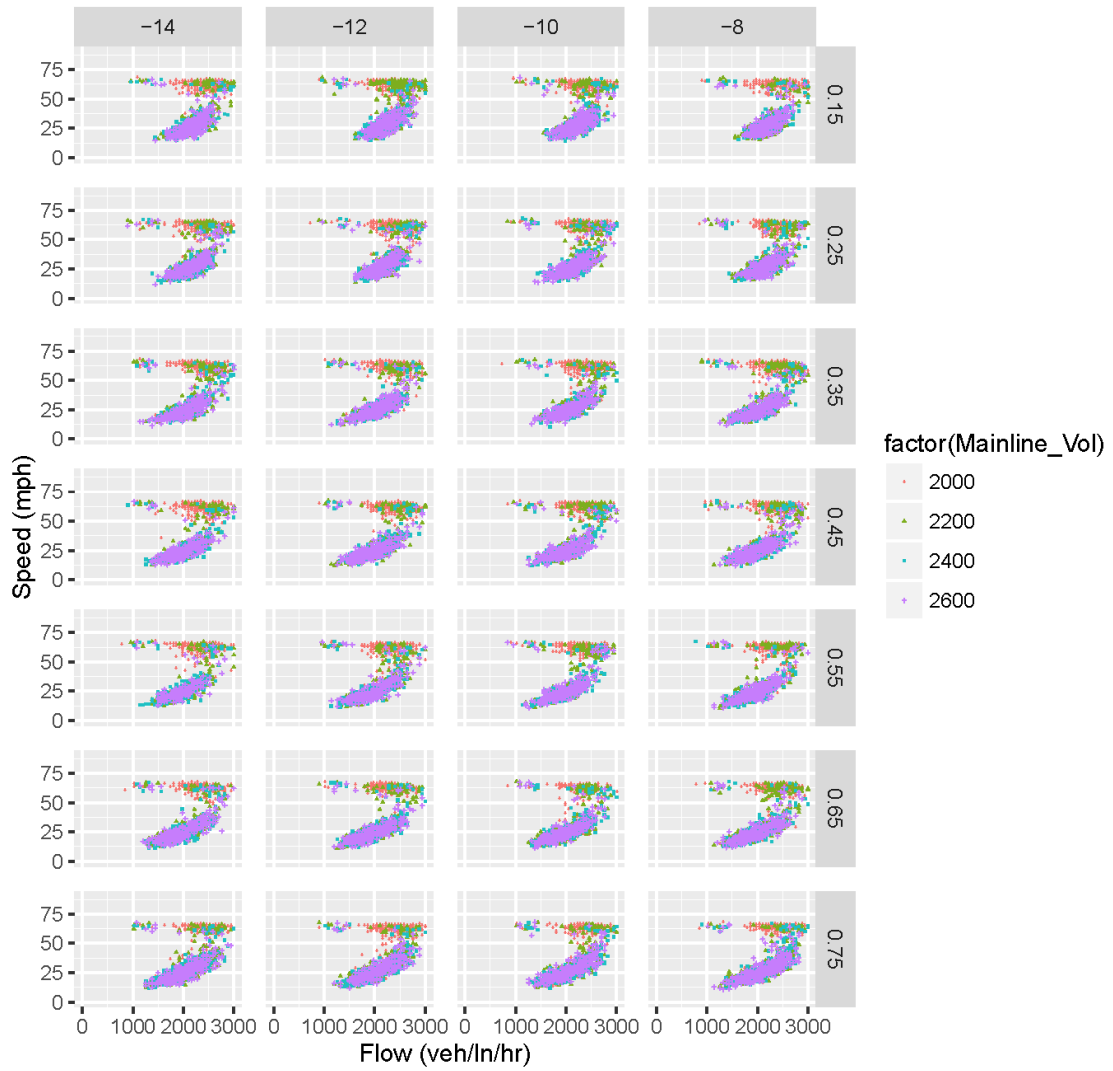


Figure 46: Speed-Flow Comparison Matrix for All Volumes at the CL.Merge with Varying Safety Factors and Coop. Braking (On-Ramp: 1,000vehs)

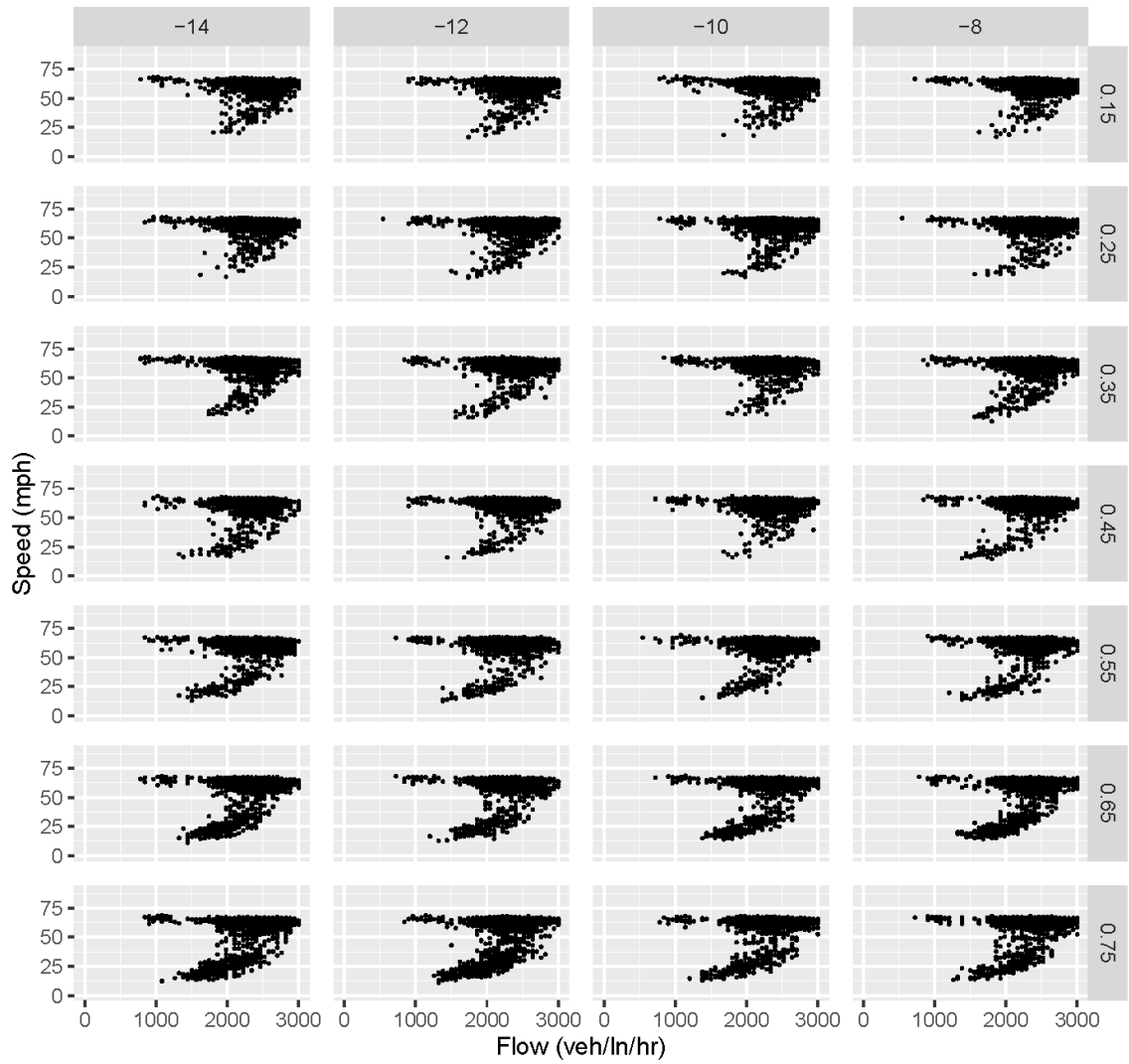


Figure 47: Speed-Flow Comparison Matrix for 2,000veh/ln at the CLMerge with Varying Safety Factors and Coop. Braking (30 Runs, On-Ramp: 1,000vehs)

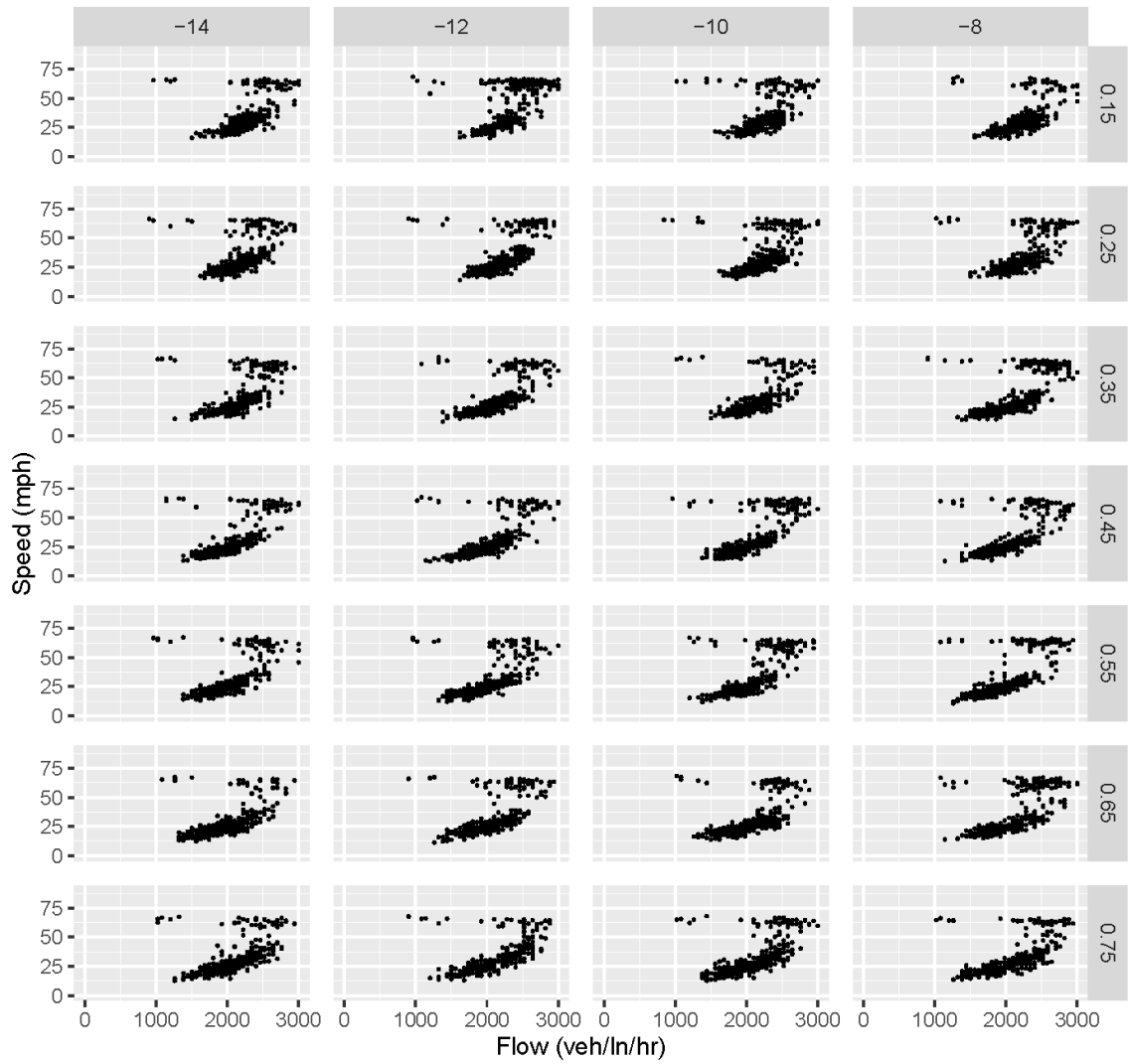


Figure 48: Speed-Flow Comparison Matrix for 2,200veh/ln at the CLMerge with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

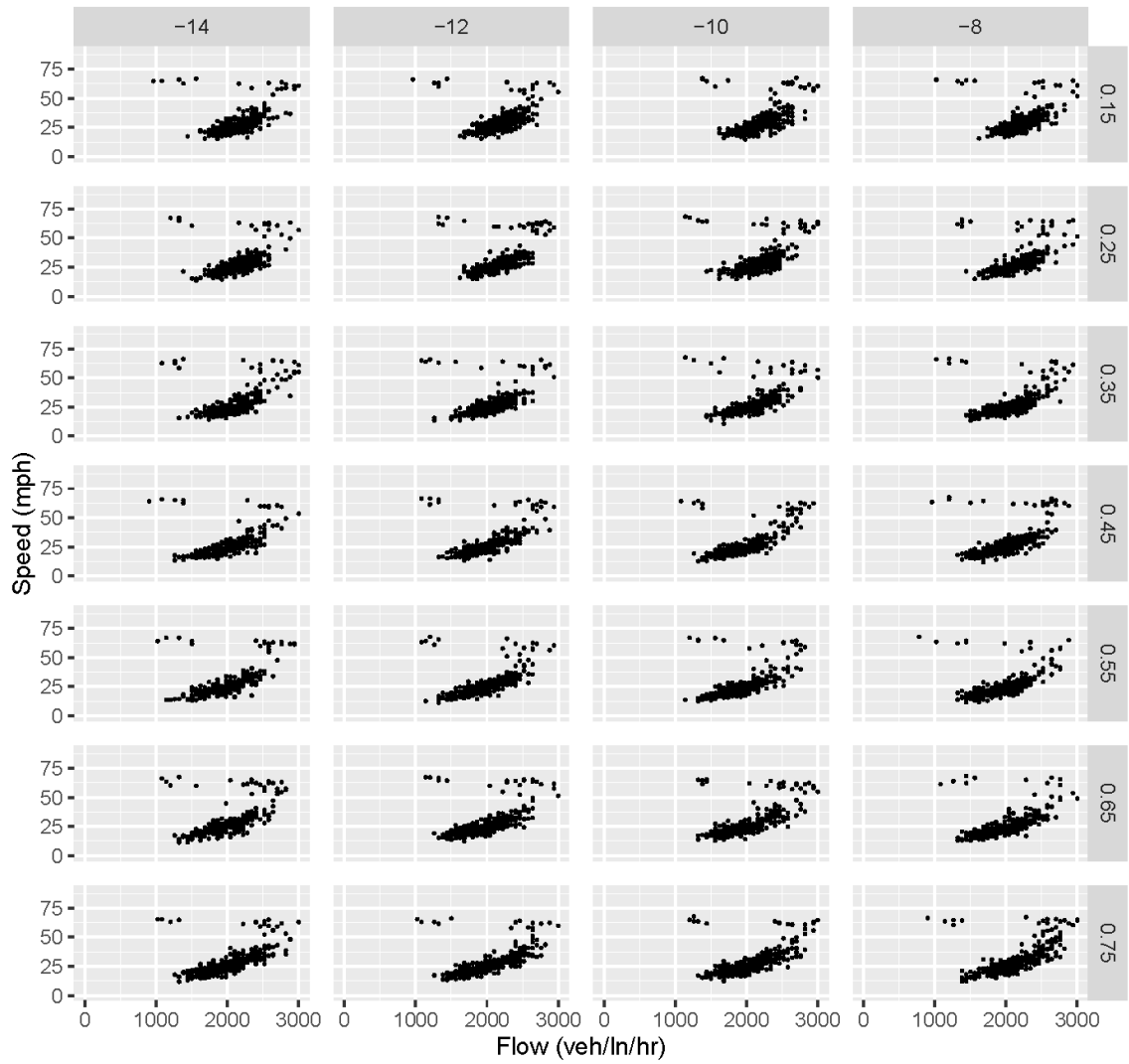


Figure 49: Speed-Flow Comparison Matrix for 2,400veh/ln at the CLMerge with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

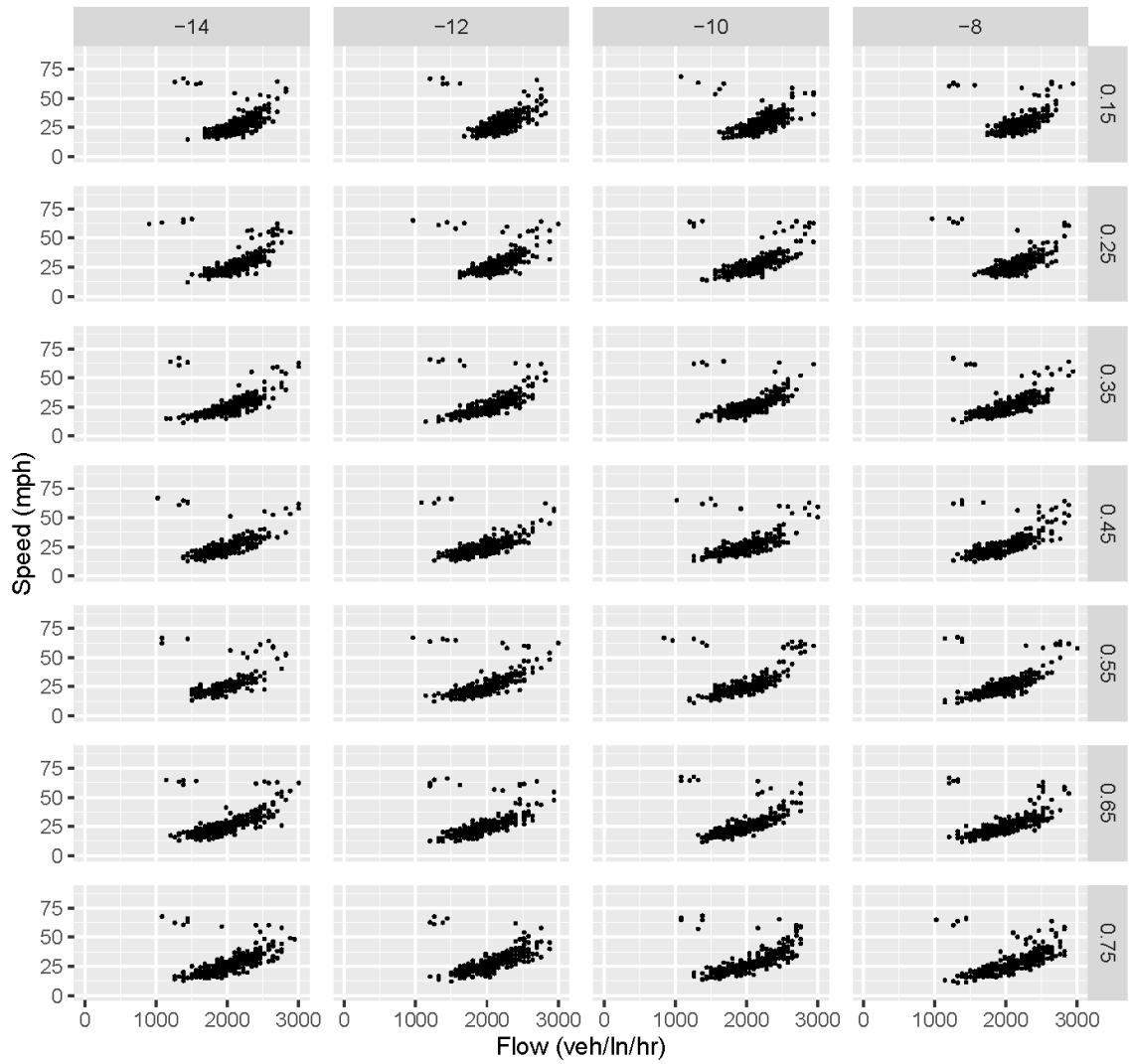


Figure 50: Speed-Flow Comparison Matrix for 2,600veh/ln at the CLMerge with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

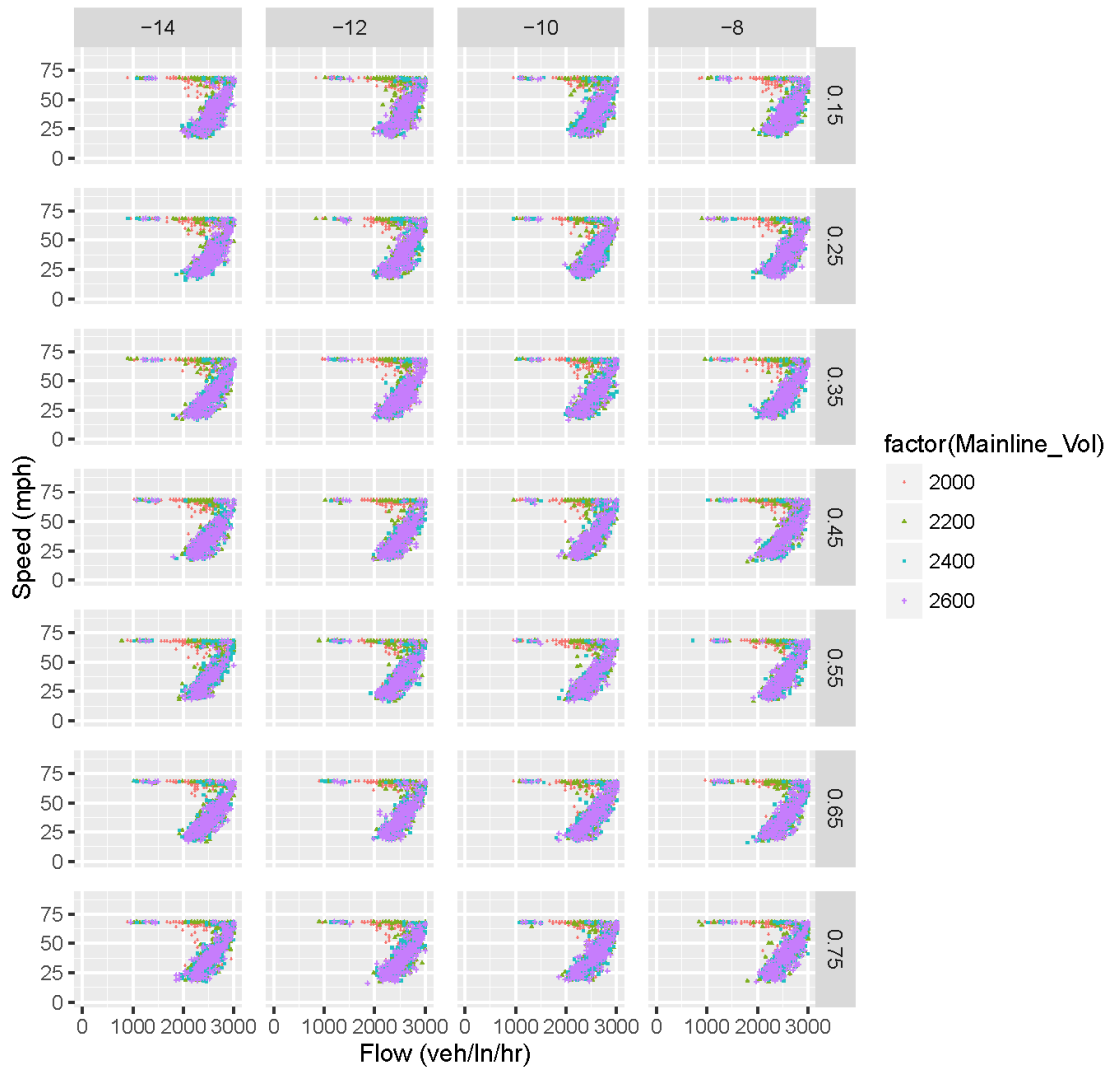


Figure 51: Speed-Flow Comparison Matrix for All Volumes at the LL.Merge with Varying Safety Factors and Coop. Braking (On-Ramp: 1,000vehs)

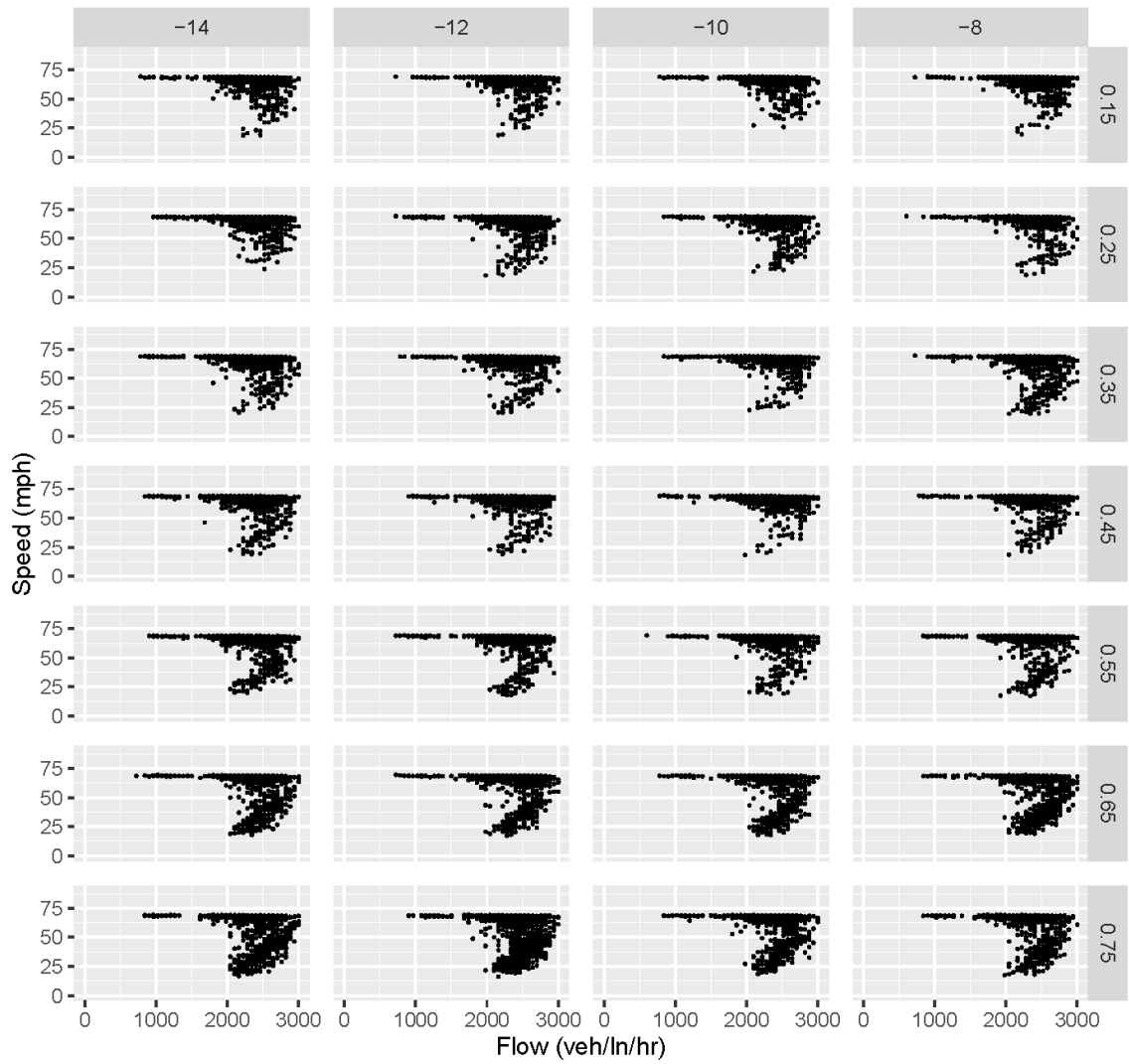


Figure 52: Speed-Flow Comparison Matrix for 2,000veh/ln at the LL.Merge with Varying Safety Factors and Coop. Braking (30 Runs, On-Ramp: 1,000vehs)

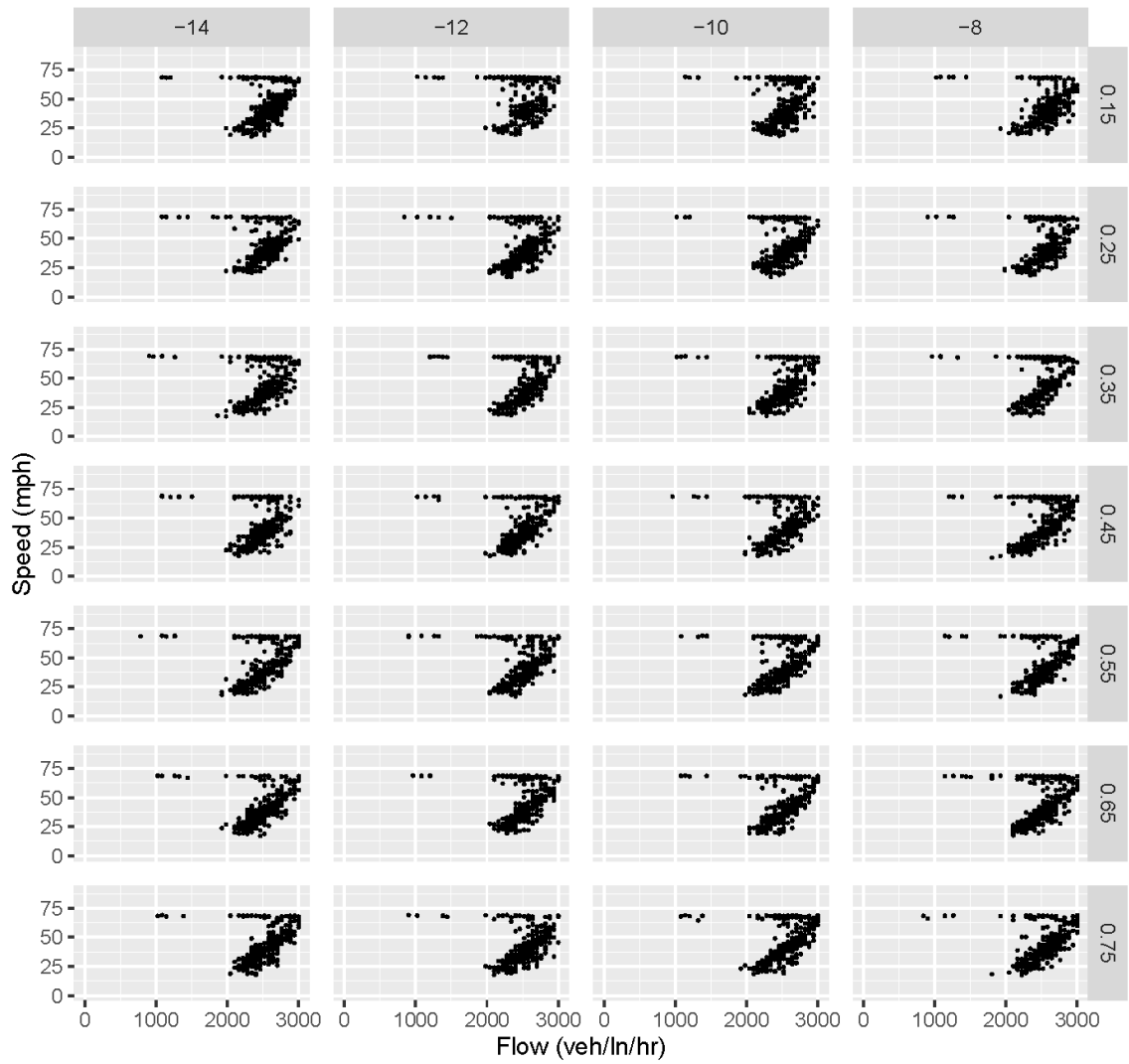


Figure 53: Speed-Flow Comparison Matrix for 2,200veh/ln at the LL.Merge with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

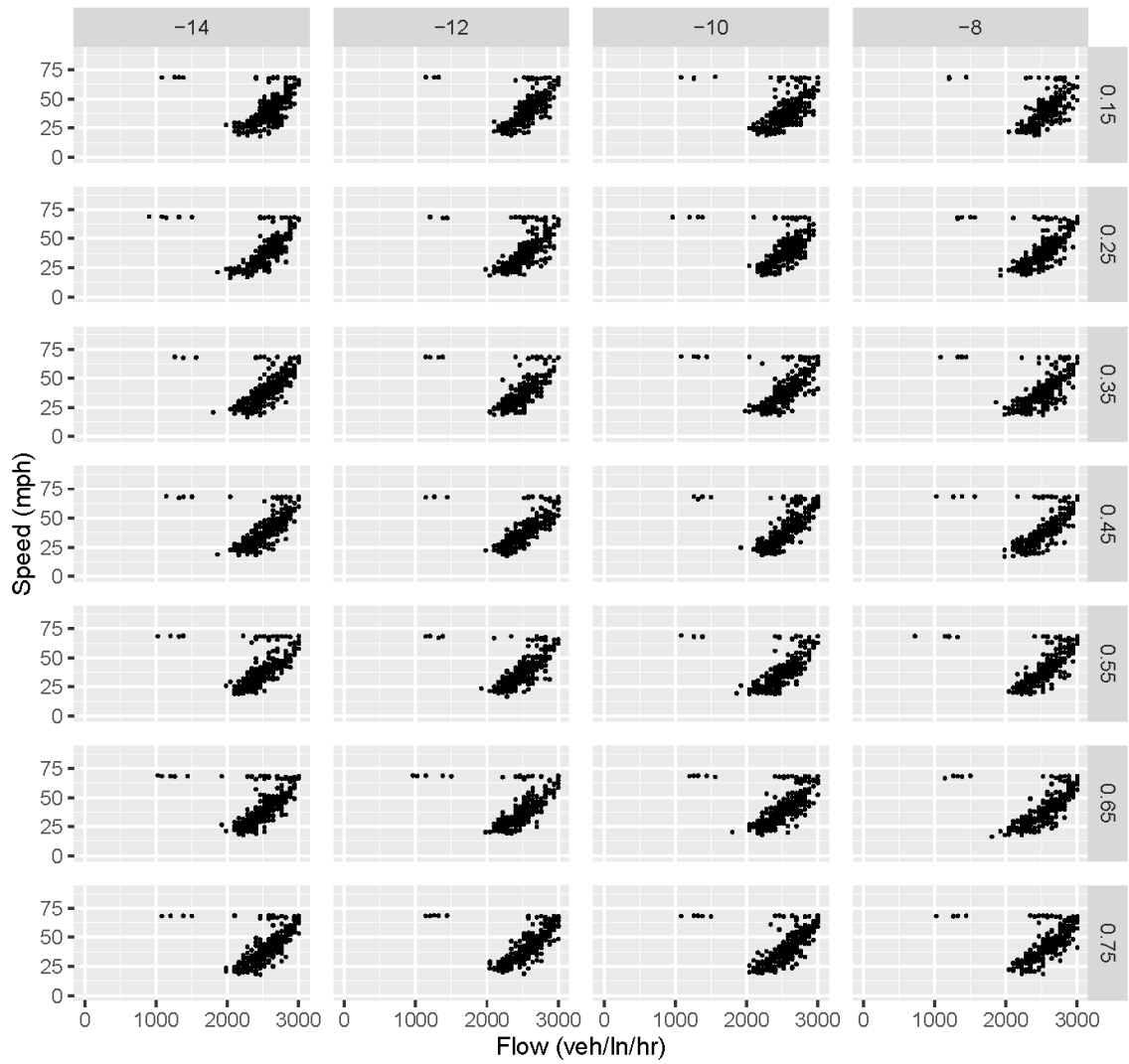


Figure 54: Speed-Flow Comparison Matrix for 2,400veh/ln at the LL.Merge with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

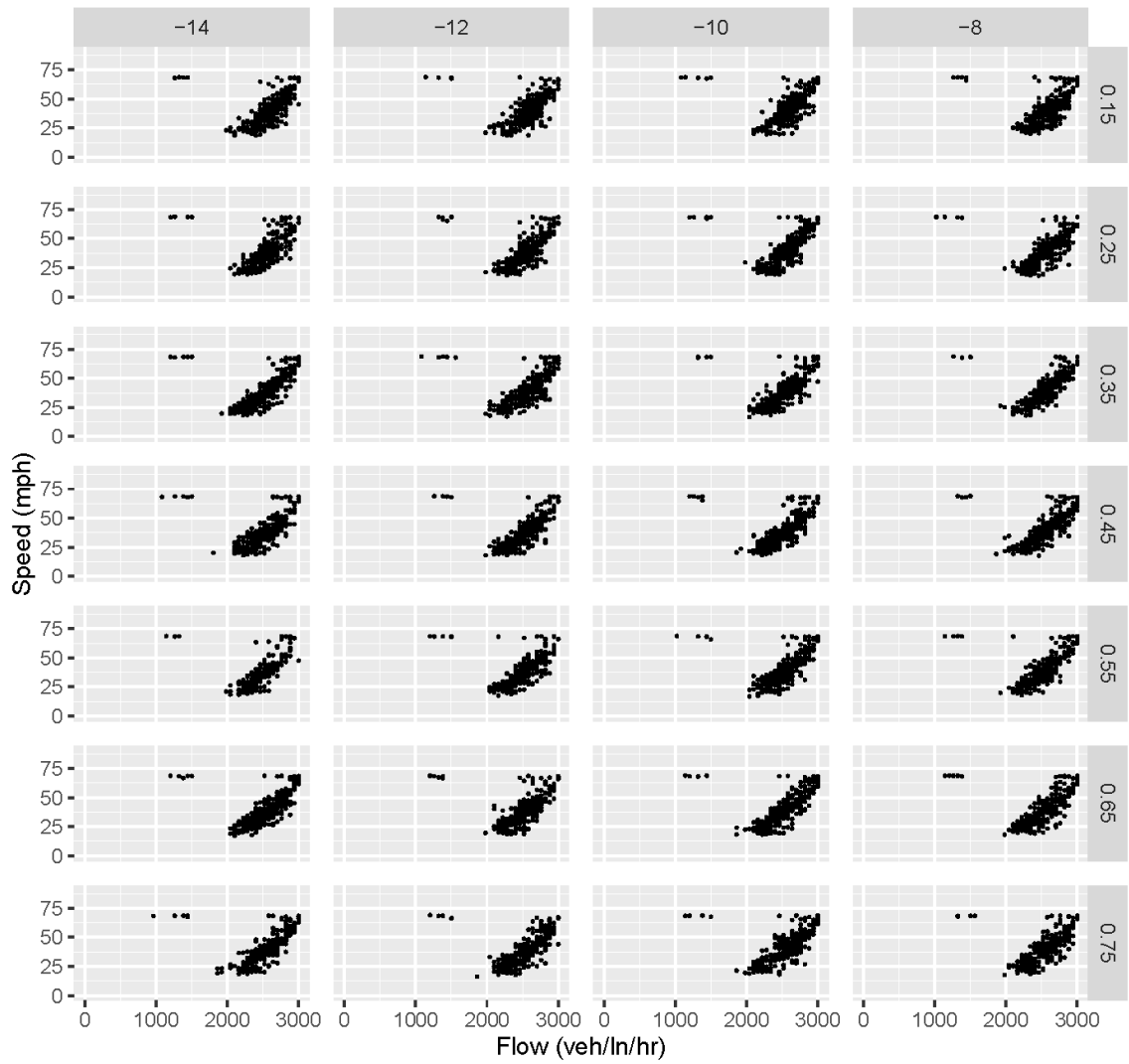


Figure 55: Speed-Flow Comparison Matrix for 2,600veh/ln at the LL.Merge with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

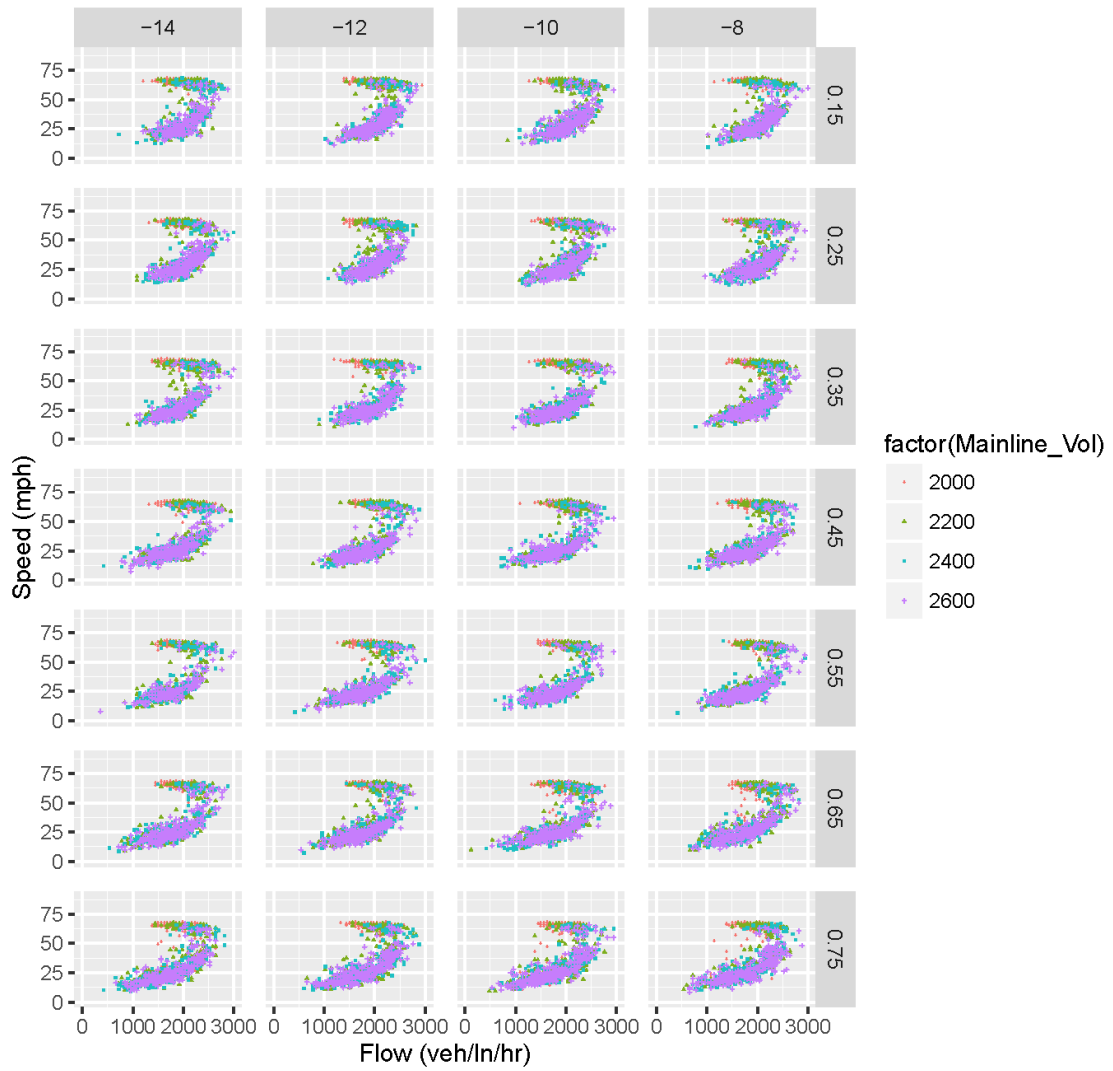


Figure 56: Speed-Flow Comparison Matrix for All Volumes at the RL.Enter with Varying Safety Factors and Coop. Braking (On-Ramp: 1,000vehs)

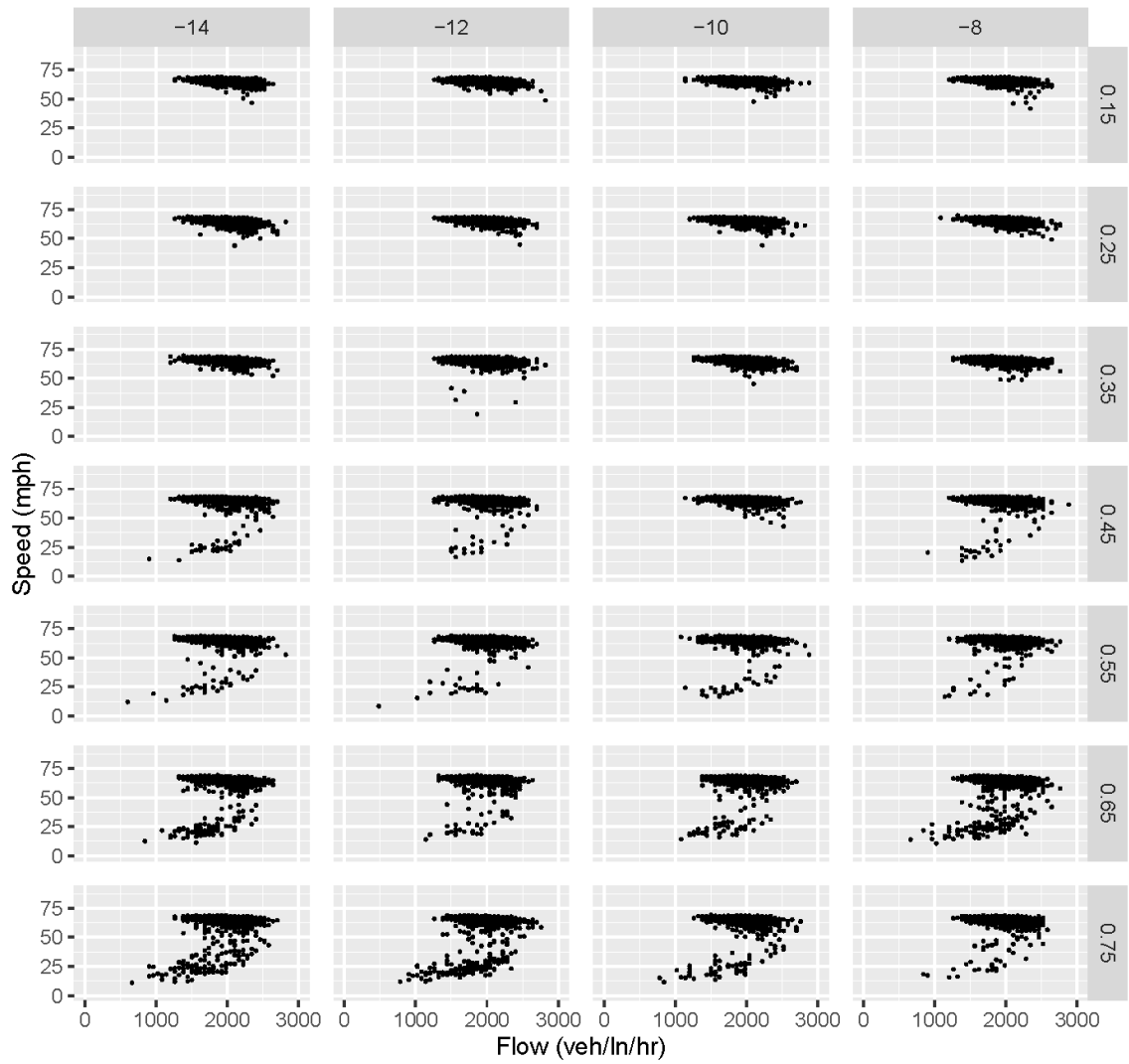


Figure 57: Speed-Flow Comparison Matrix for 2,000veh/ln at the RL.Enter with Varying Safety Factors and Coop. Braking (30 Runs, On-Ramp: 1,000vehs)

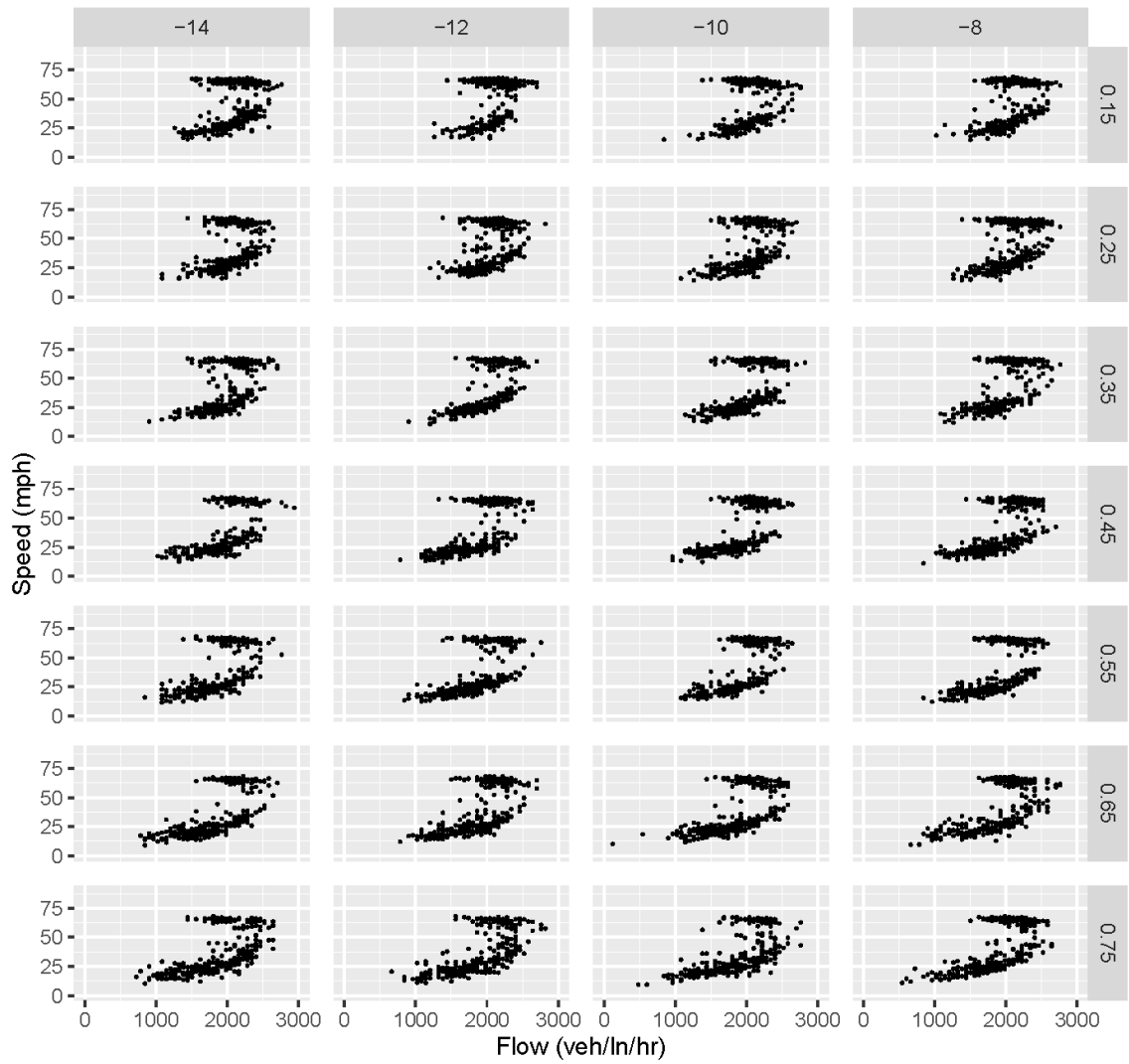


Figure 58: Speed-Flow Comparison Matrix for 2,200veh/ln at the RL.Enter with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

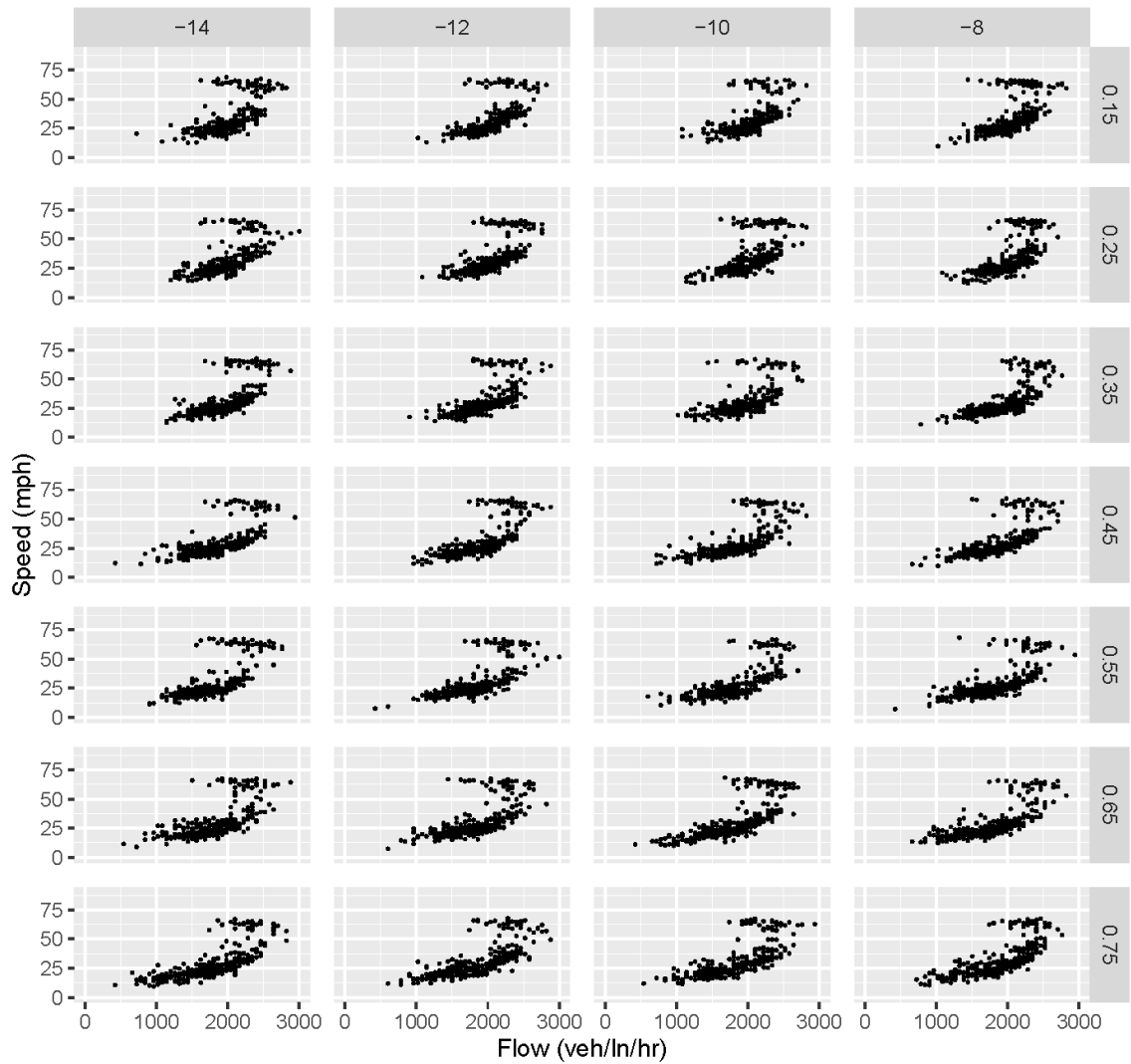


Figure 59: Speed-Flow Comparison Matrix for 2,400veh/ln at the RL.Enter with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

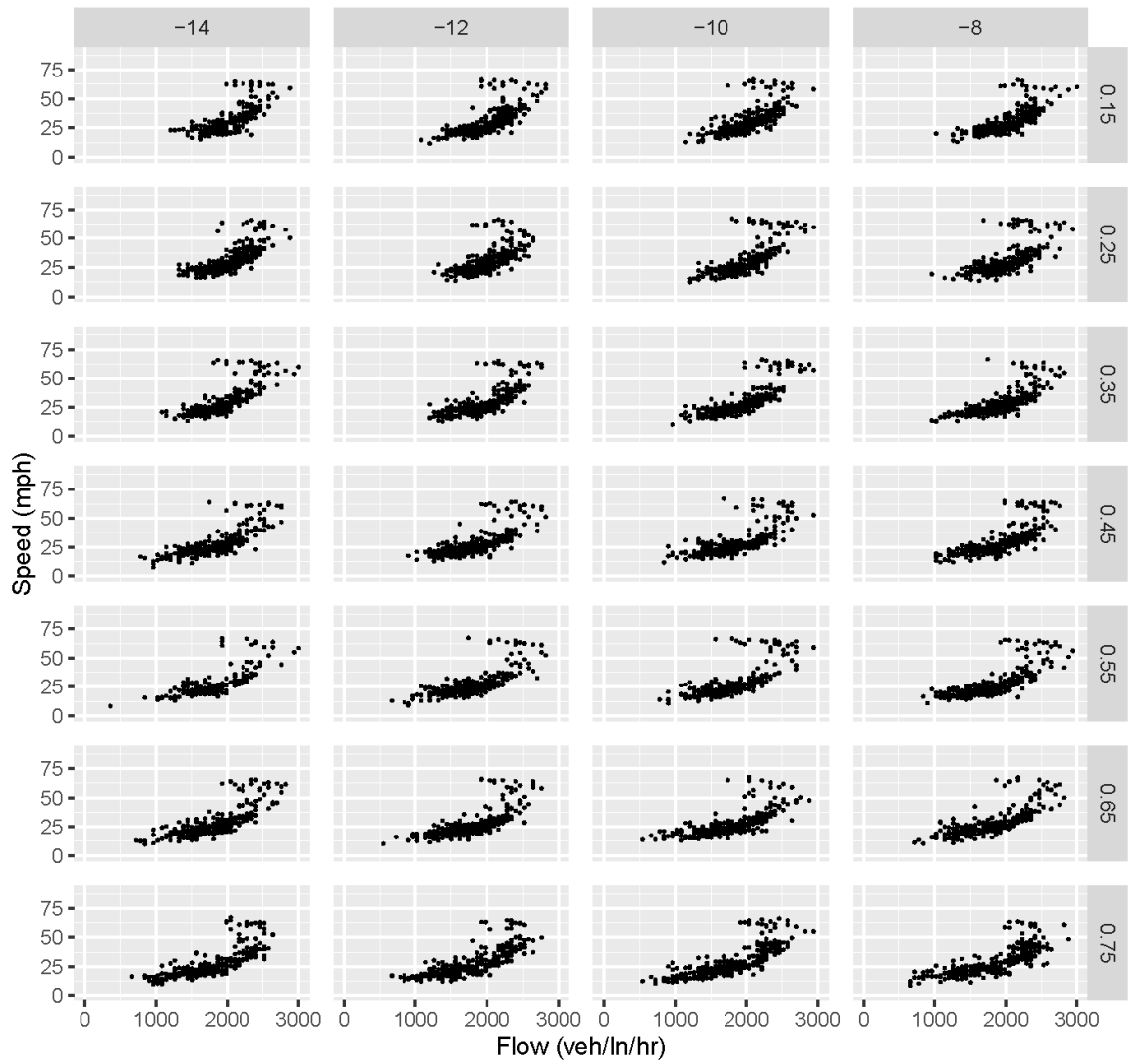


Figure 60: Speed-Flow Comparison Matrix for 2,600veh/ln at the RL.Enter with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

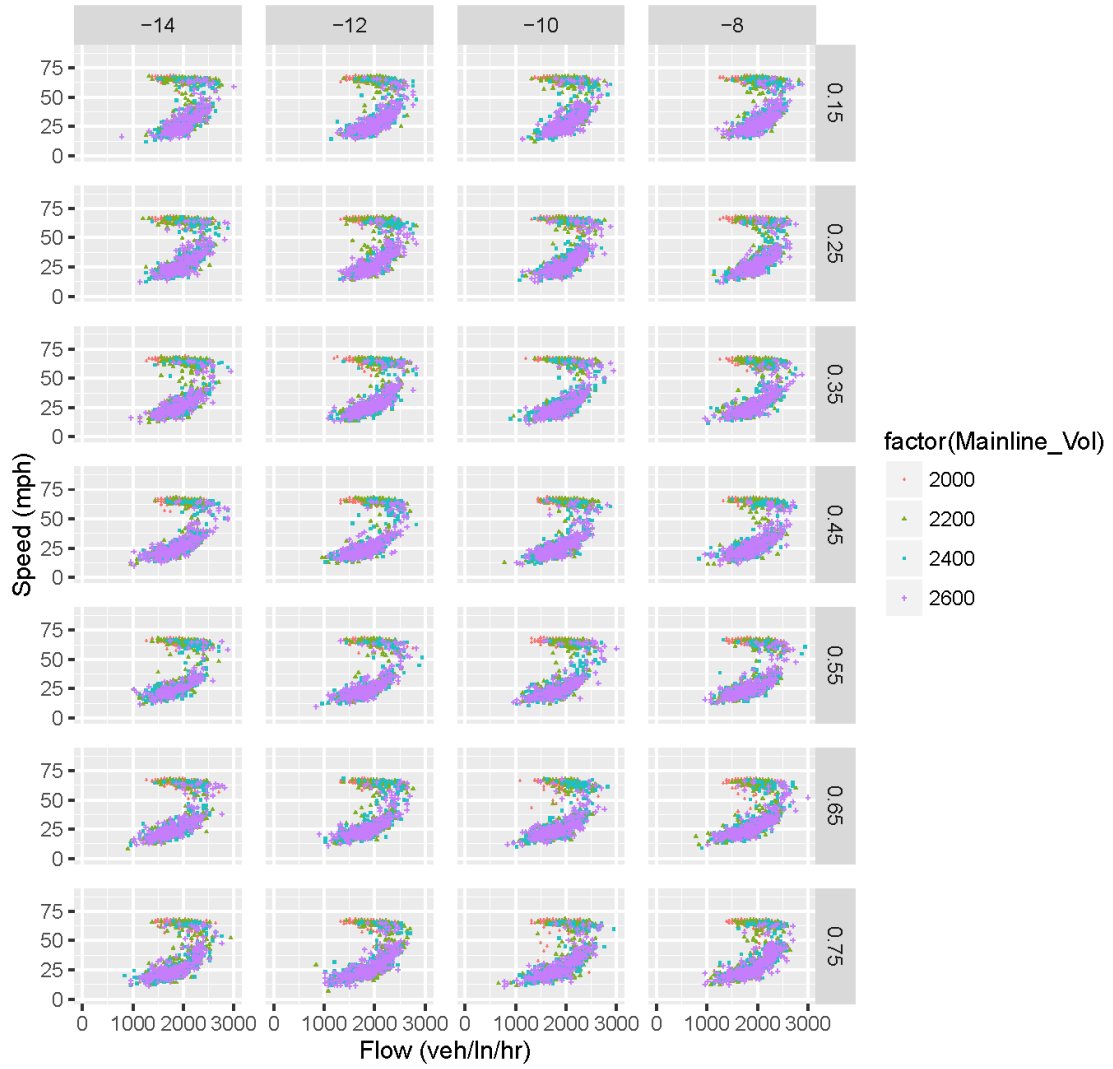


Figure 61: Speed-Flow Comparison Matrix for All Volumes at the CL.Enter with Varying Safety Factors and Coop. Braking (On-Ramp: 1,000vehs)

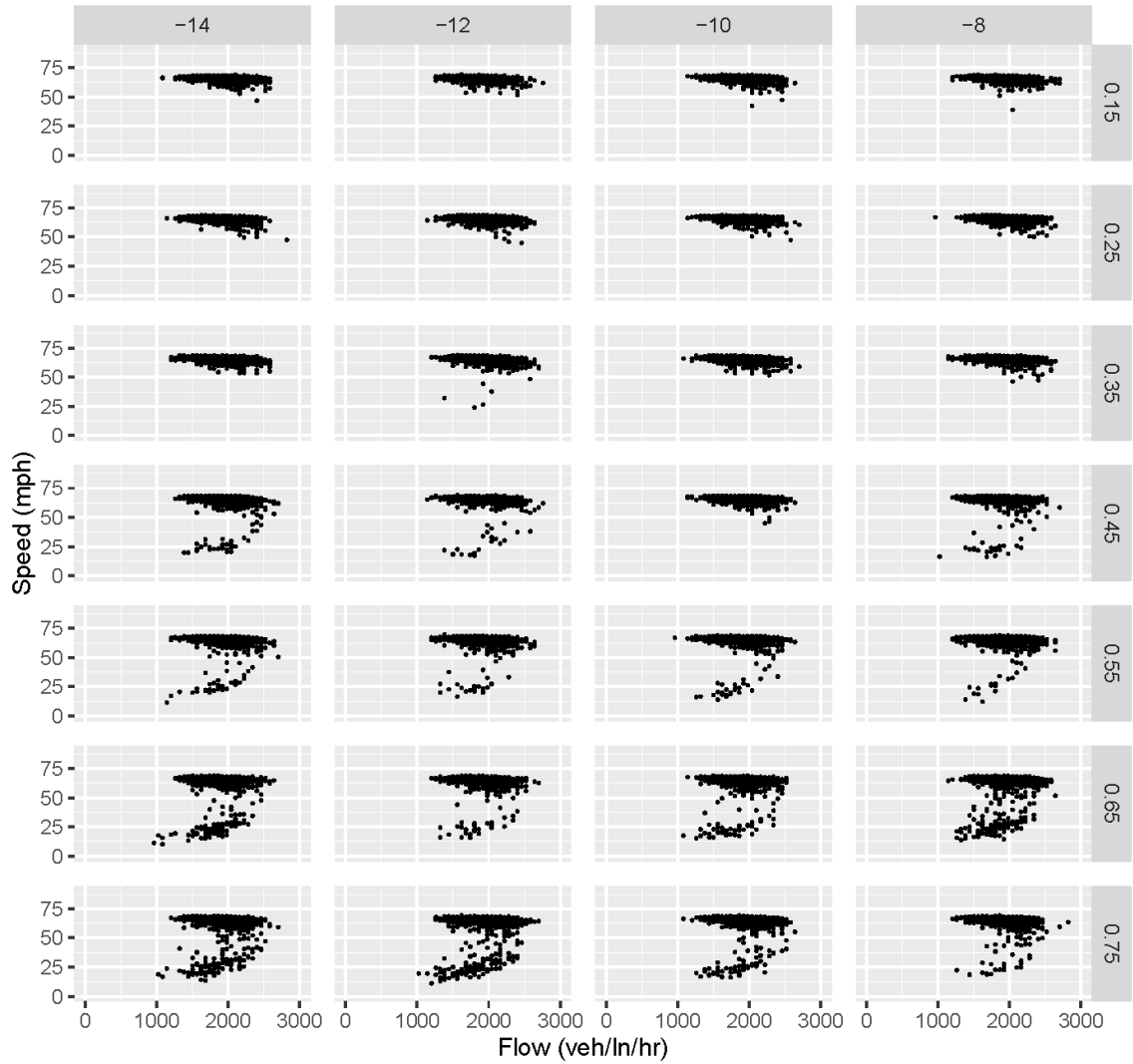


Figure 62: Speed-Flow Comparison Matrix for 2,000veh/ln at the CL.Enter with Varying Safety Factors and Coop. Braking (30 Runs, On-Ramp: 1,000vehs)

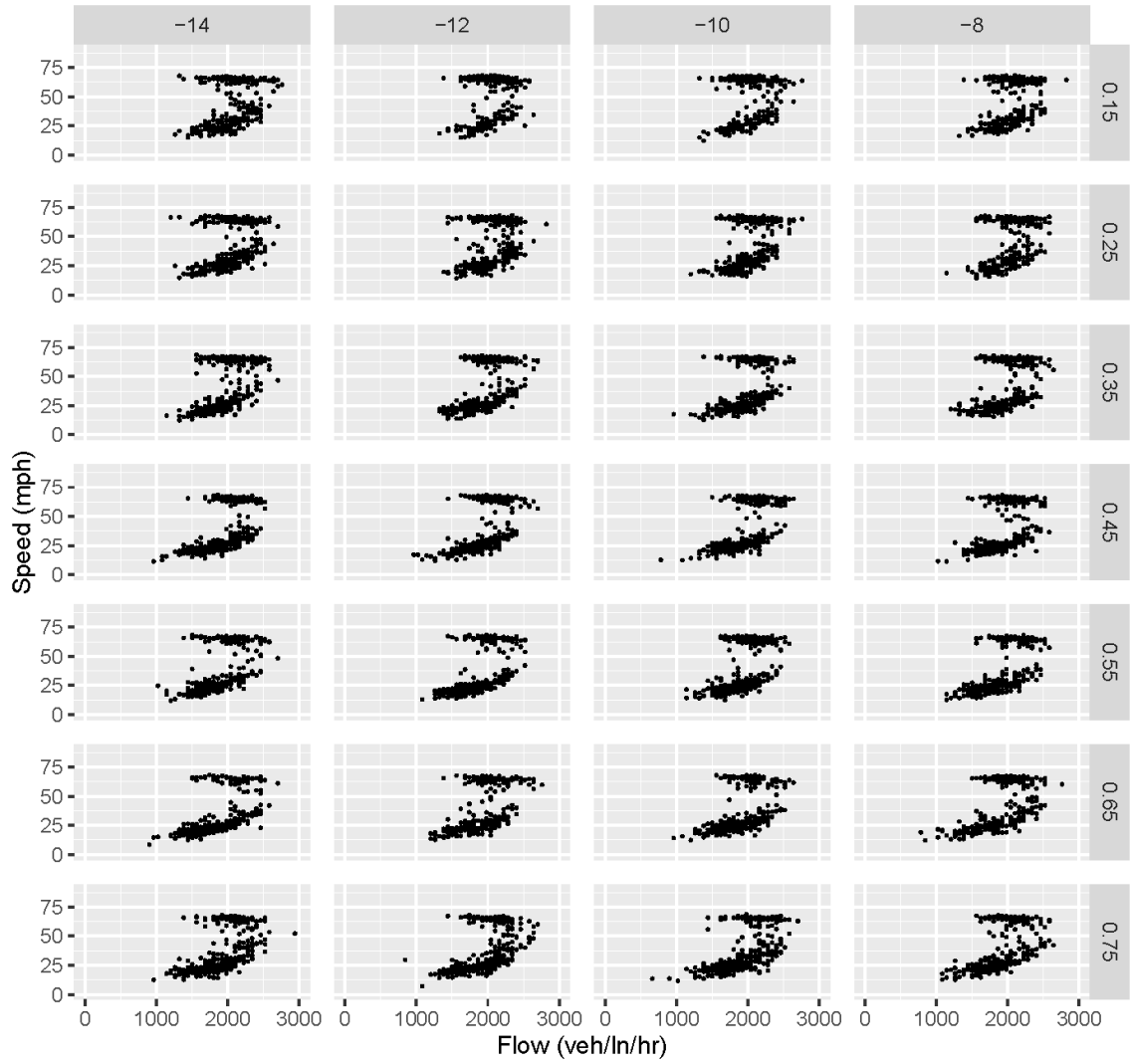


Figure 63: Speed-Flow Comparison Matrix for 2,200veh/ln at the CL.Enter with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

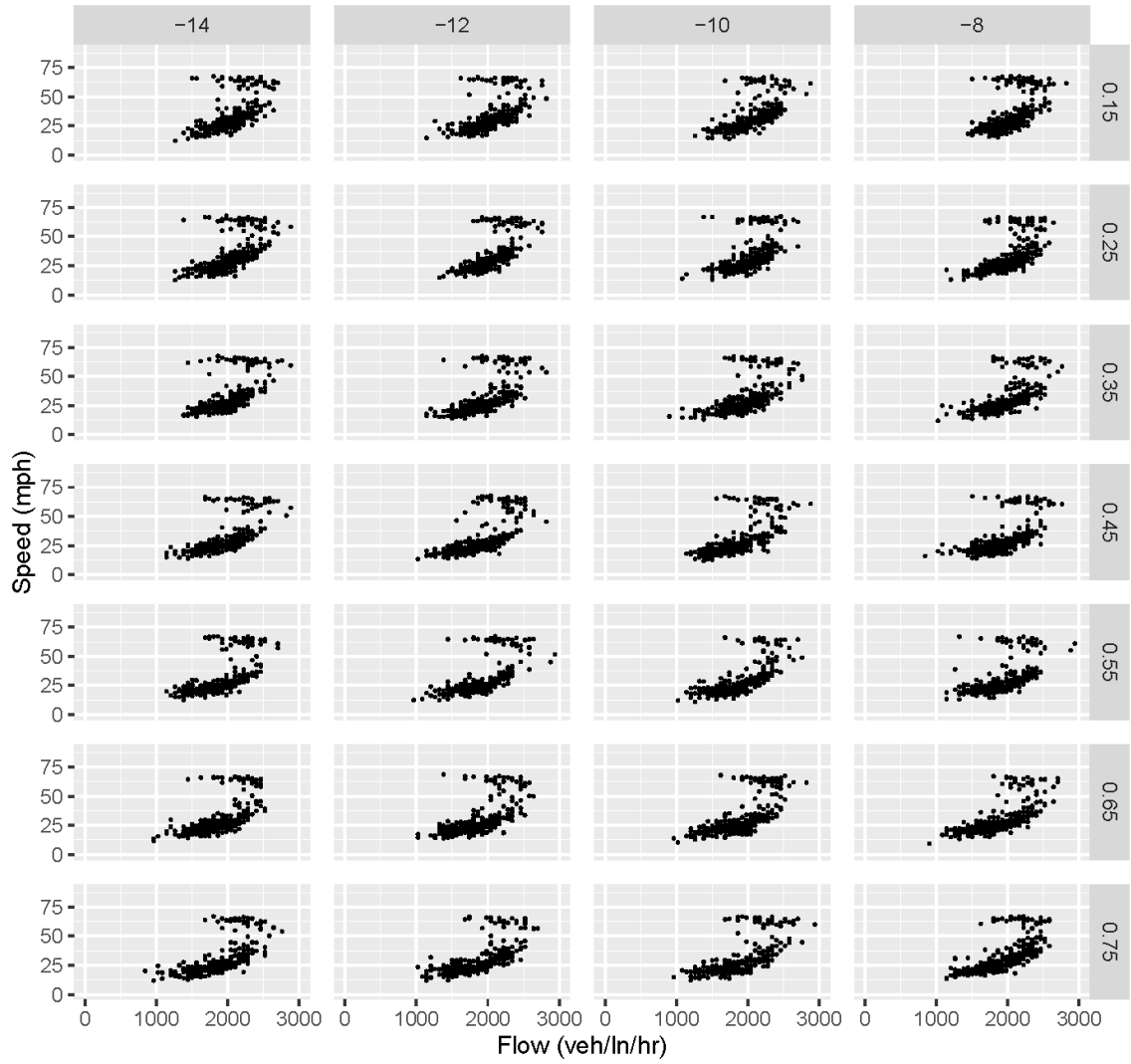


Figure 64: Speed-Flow Comparison Matrix for 2,400veh/ln at the CL.Enter with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

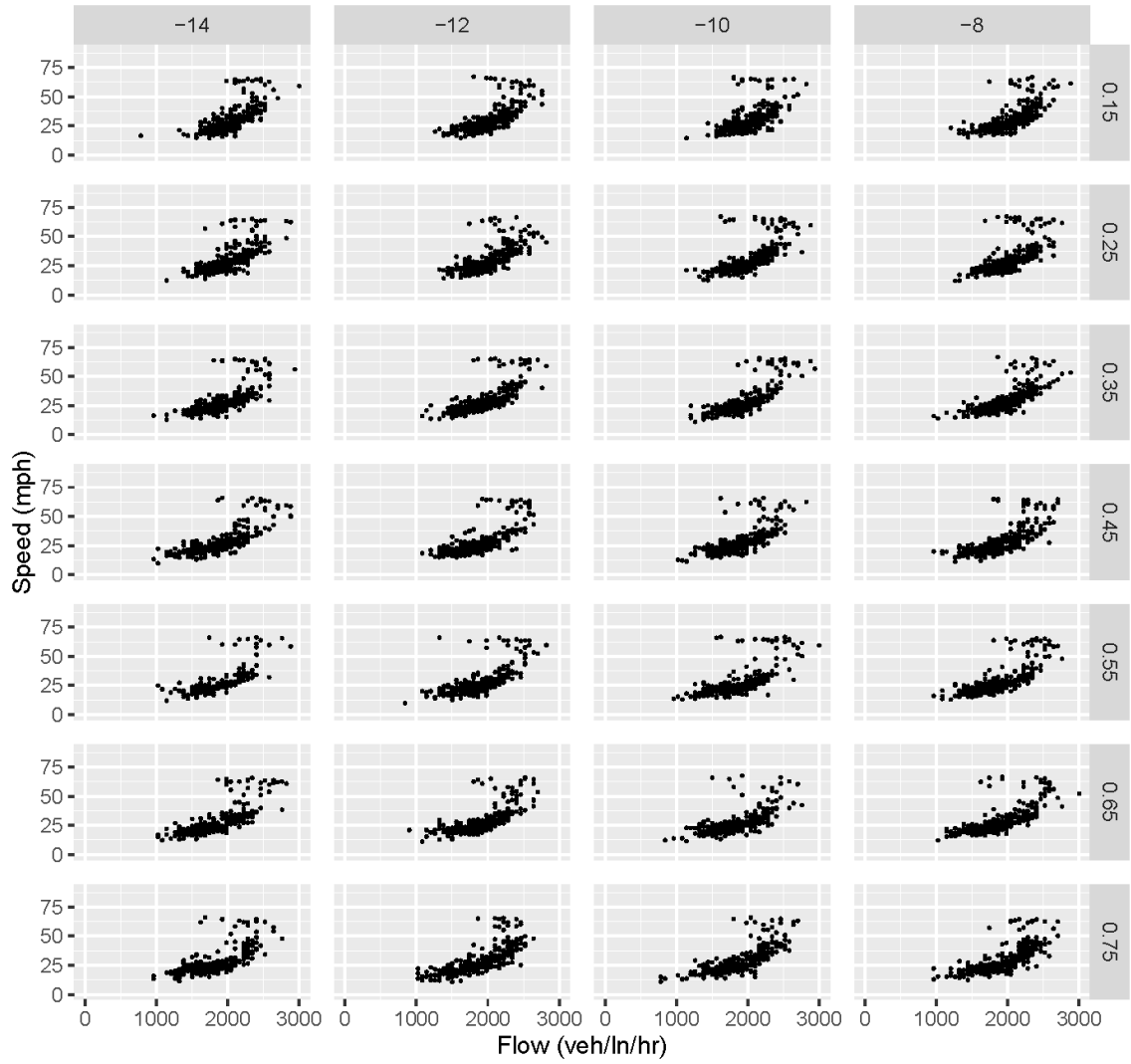


Figure 65: Speed-Flow Comparison Matrix for 2,600veh/ln at the CL.Enter with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

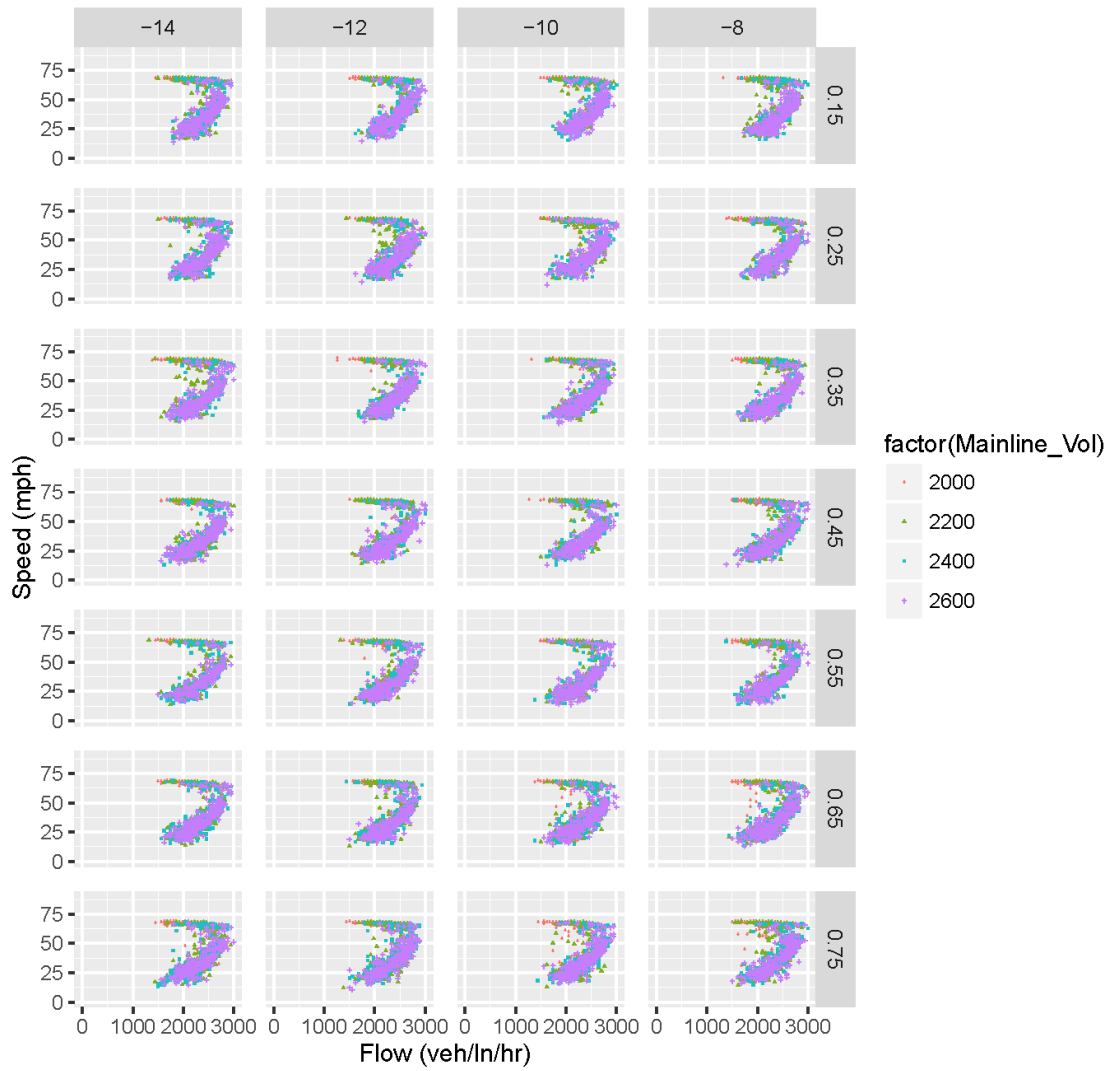


Figure 66: Speed-Flow Comparison Matrix for All Volumes at the LL.Enter with Varying Safety Factors and Coop. Braking (On-Ramp: 1,000vehs)

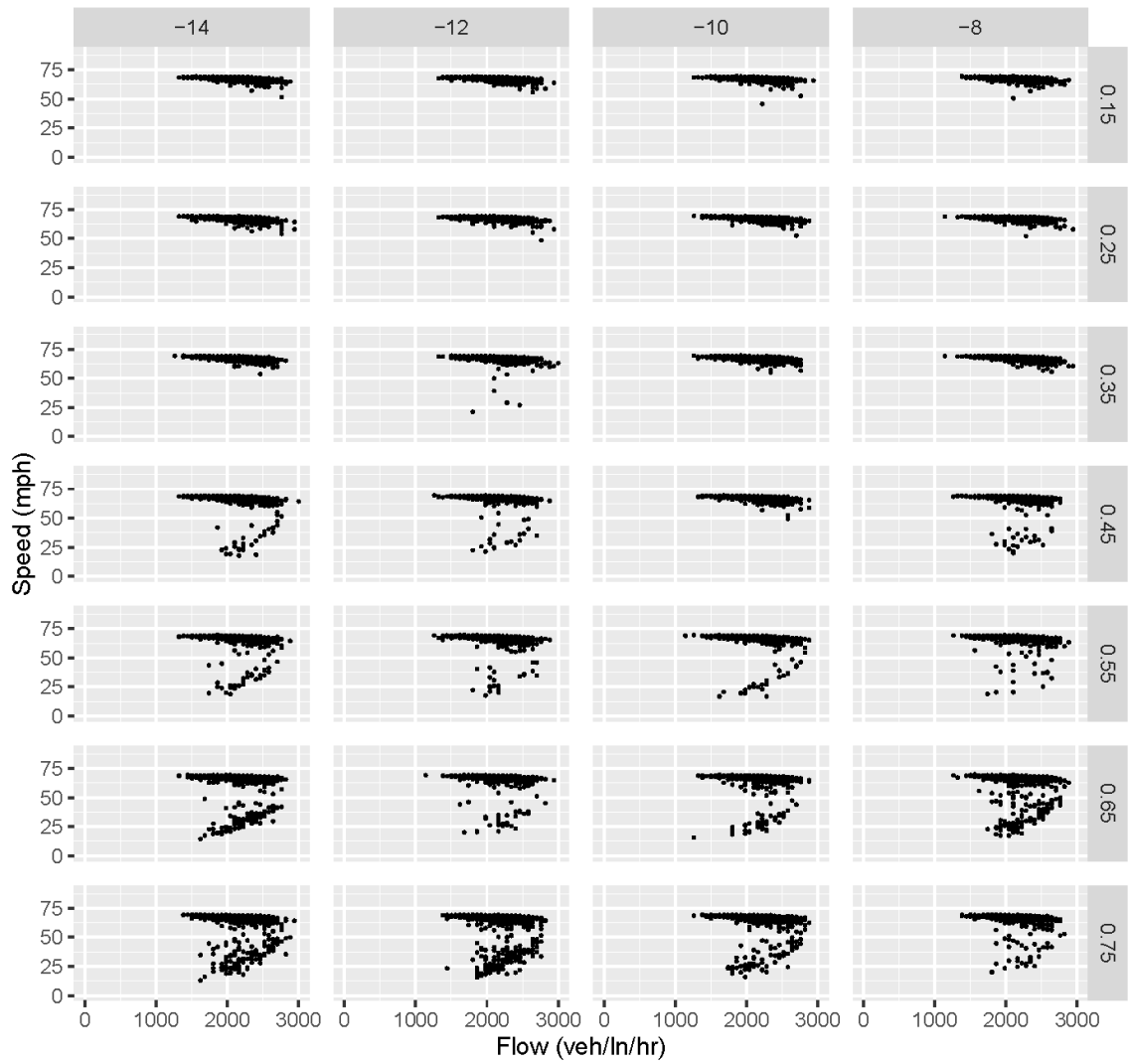


Figure 67: Speed-Flow Comparison Matrix for 2,000veh/ln at the LL.Enter with Varying Safety Factors and Coop. Braking (30 Runs, On-Ramp: 1,000vehs)

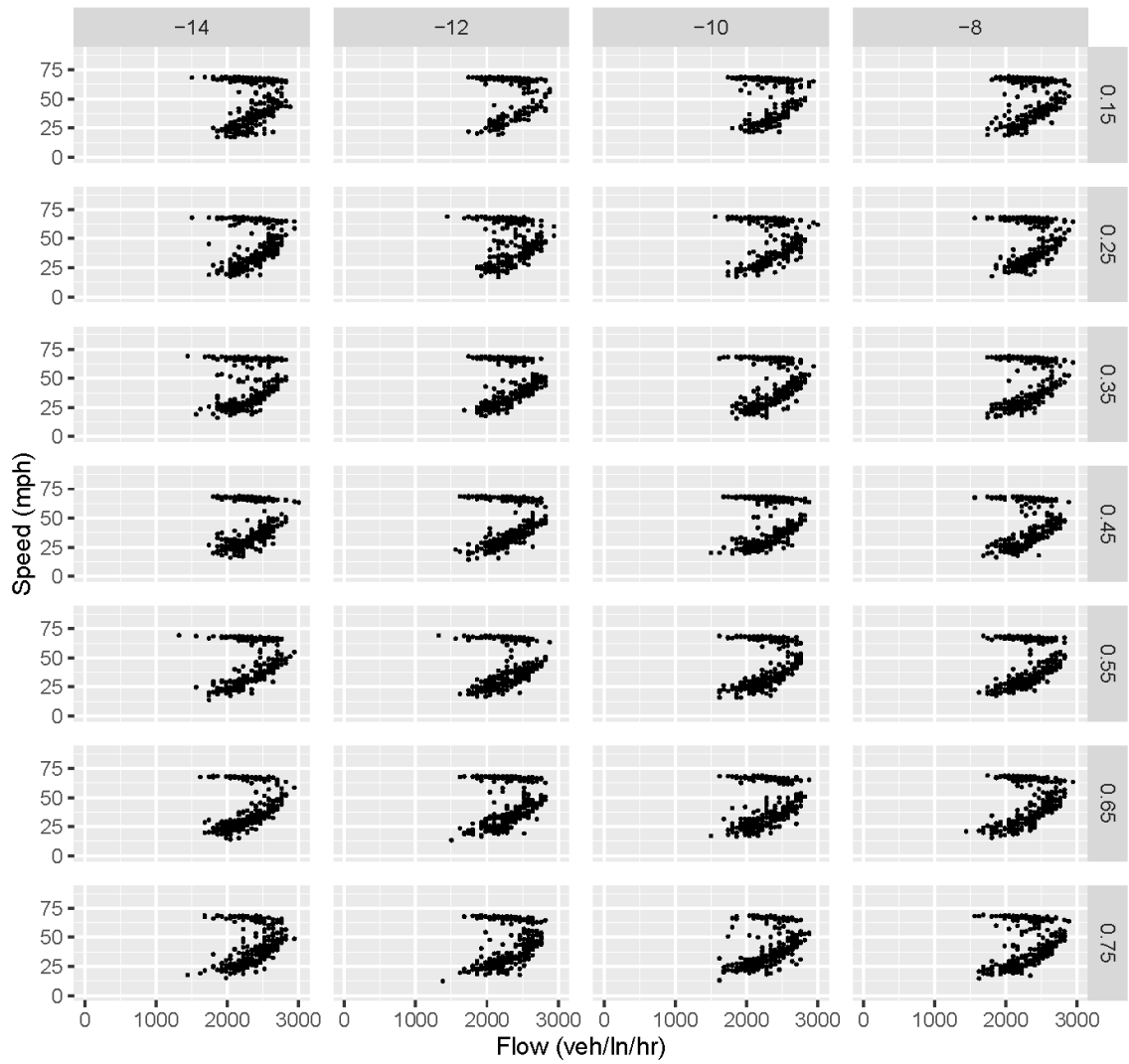


Figure 68: Speed-Flow Comparison Matrix for 2,200veh/ln at the LL.Enter with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

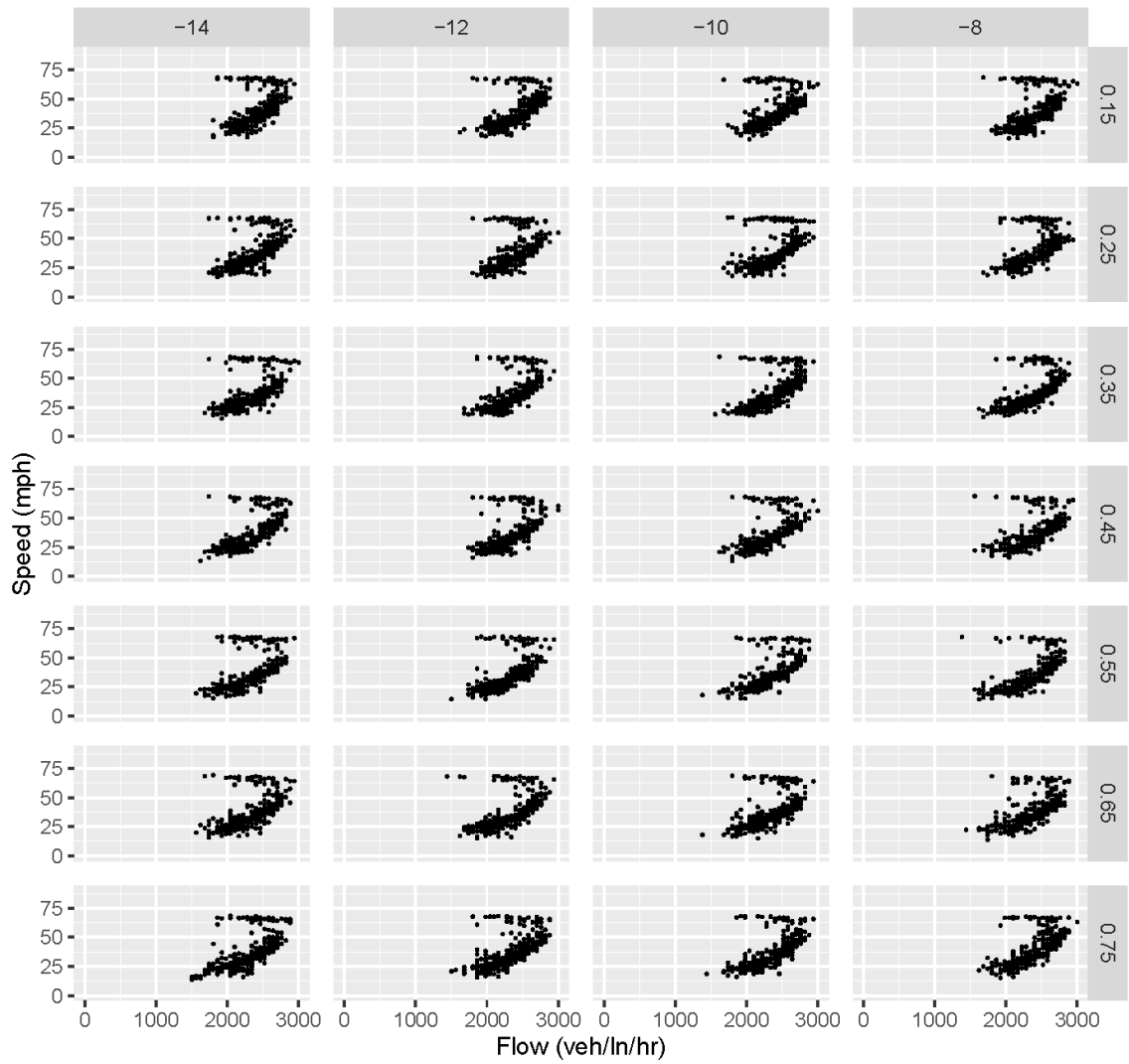


Figure 69: Speed-Flow Comparison Matrix for 2,400veh/ln at the LL.Enter with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

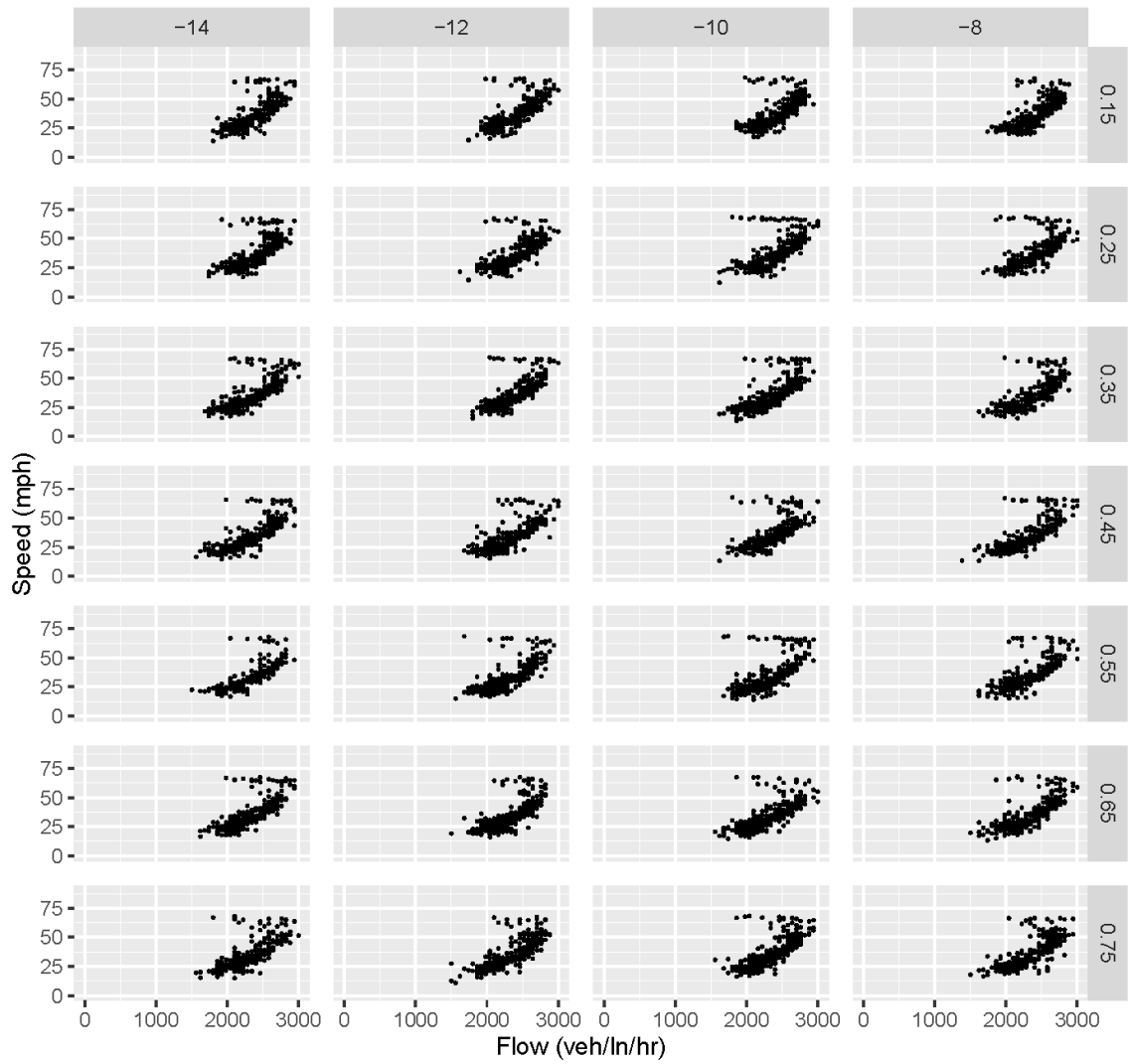


Figure 70: Speed-Flow Comparison Matrix for 2,600veh/ln at the LL.Enter with Varying Safety Factors and Coop. Braking (5 Runs, On-Ramp: 1,000vehs)

APPENDIX E

ADDITIONAL INCREMENTAL DESIRED SPEED ALGORITHM

SPEED-FLOW COMPARISON MATRICES

The additional speed-flow comparison matrices within Appendix E have been ordered as follows: CL.Merge, LL.Merge, RL.Enter, CL.Enter and LL.Enter. The first figure for each data collection point will be of all the data points plotted followed by three more figures with each mainline volume plotted individually.

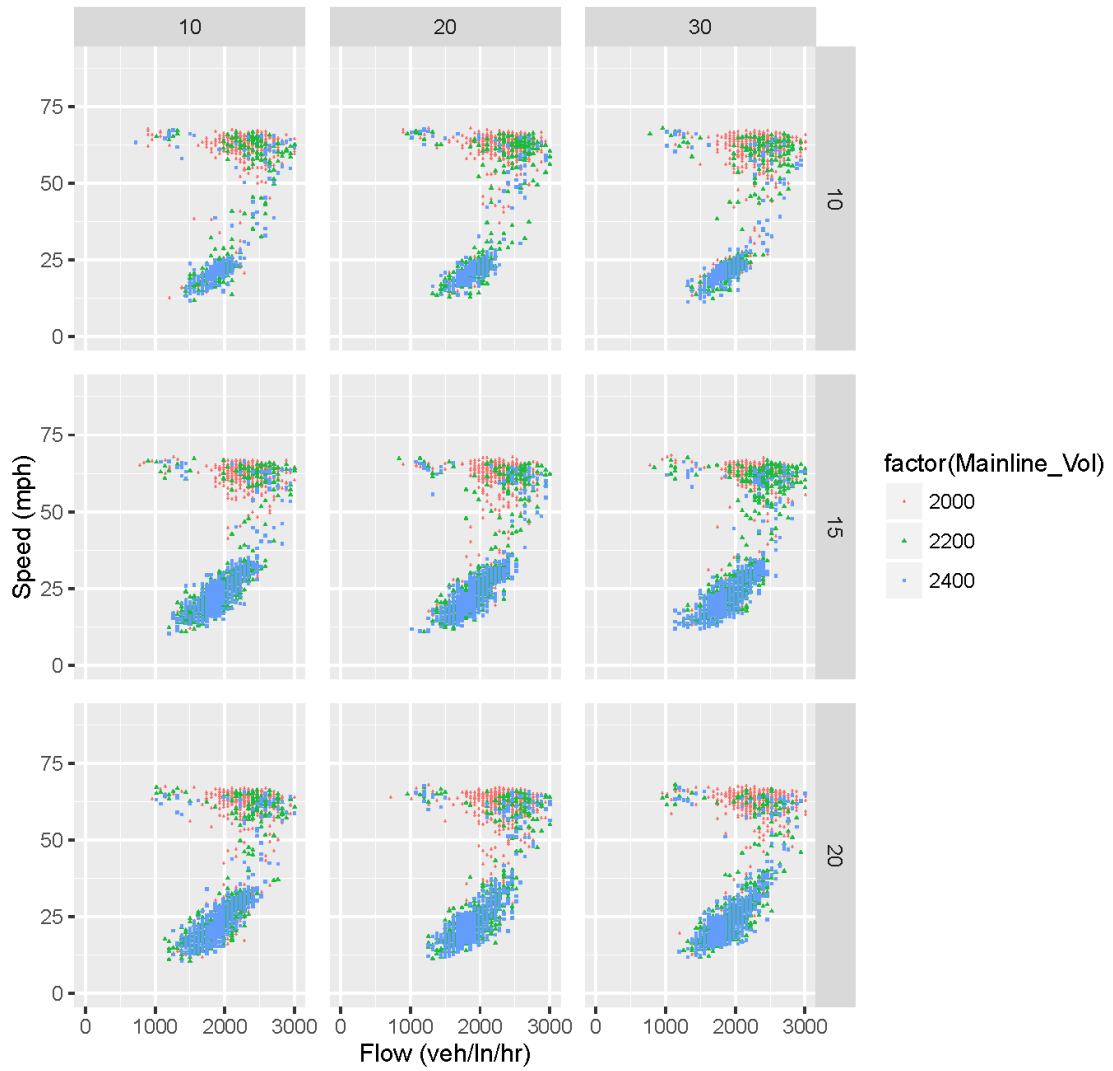


Figure 71: Speed-Flow Comparison Matrix for All Volumes at the CL.Merge with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

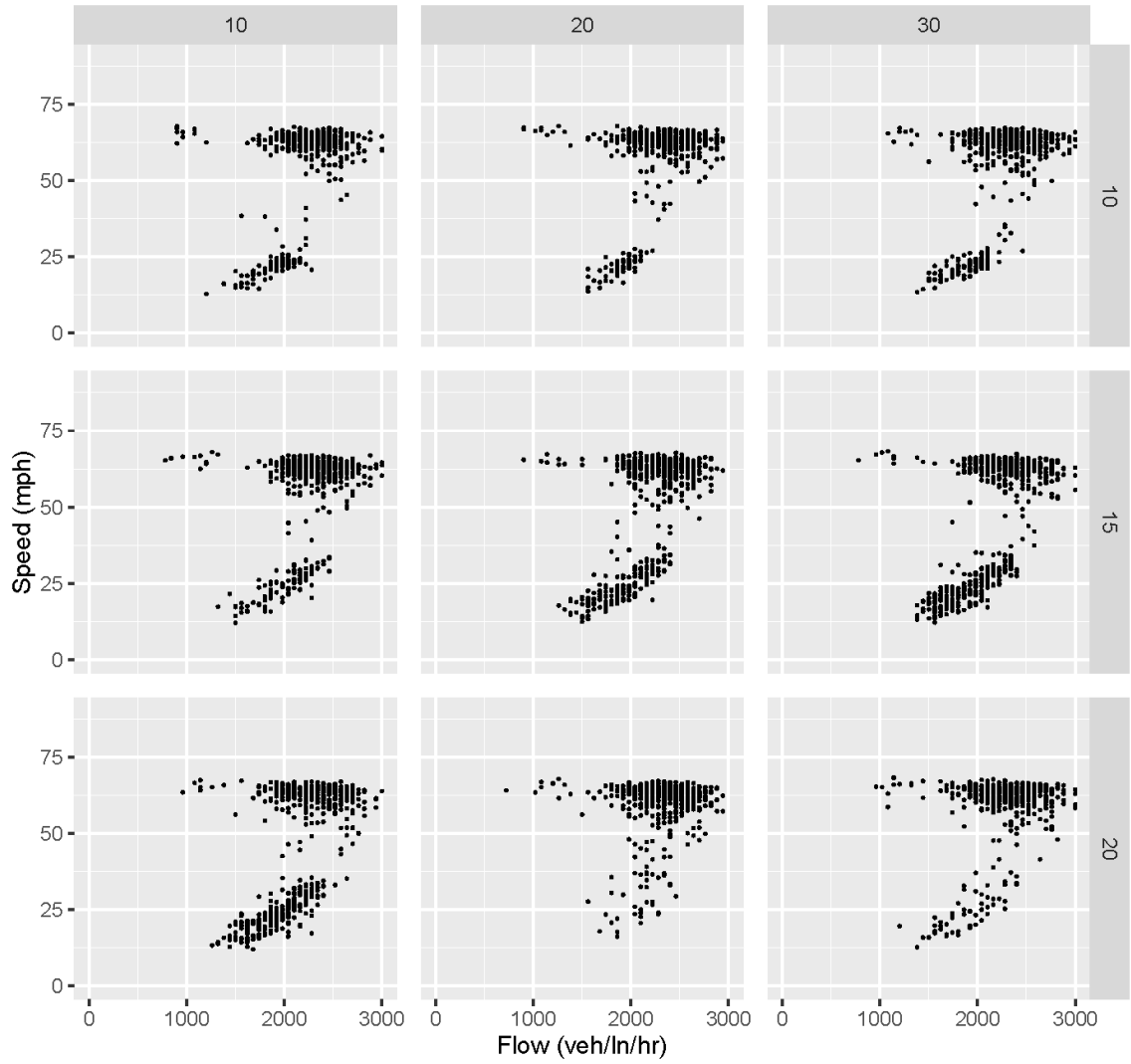


Figure 72: Speed-Flow Comparison Matrix for 2,000veh/ln at the CL.Merge with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

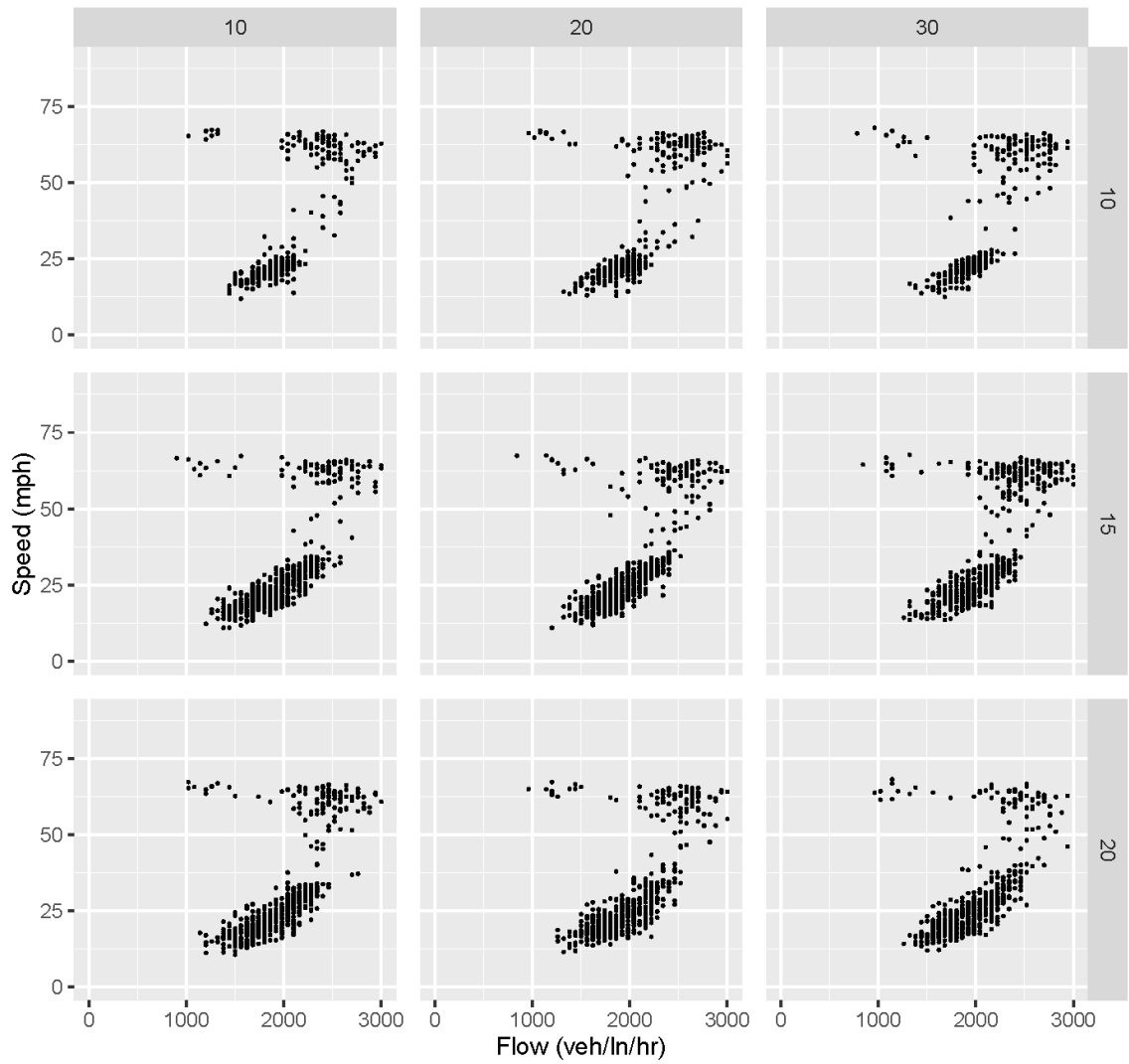


Figure 73: Speed-Flow Comparison Matrix for 2,200veh/ln at the CL.Merge with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

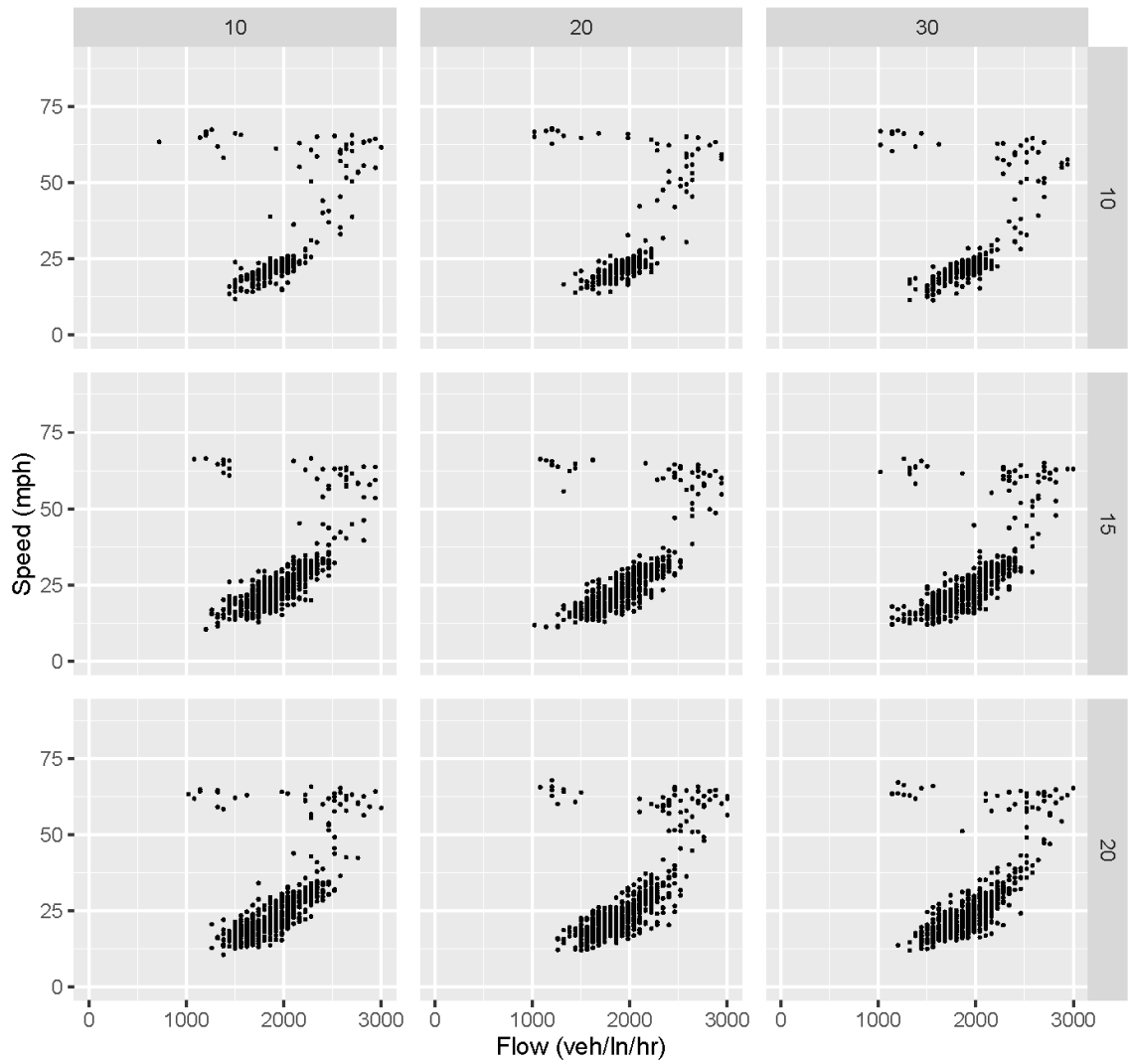


Figure 74: Speed-Flow Comparison Matrix for 2,400veh/ln at the CL.Merge with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

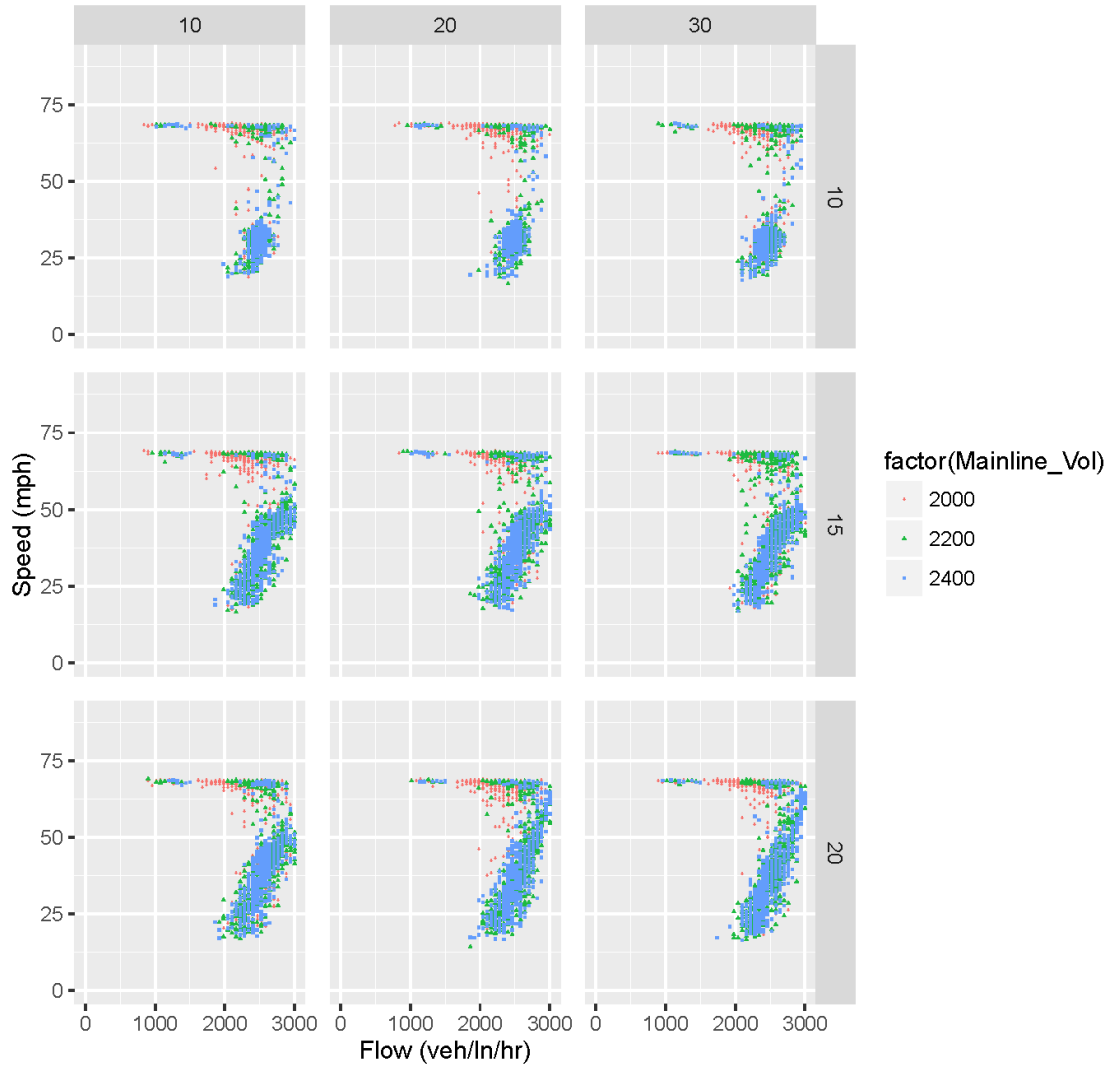


Figure 75: Speed-Flow Comparison Matrix for All Volumes at the LL.Merge with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

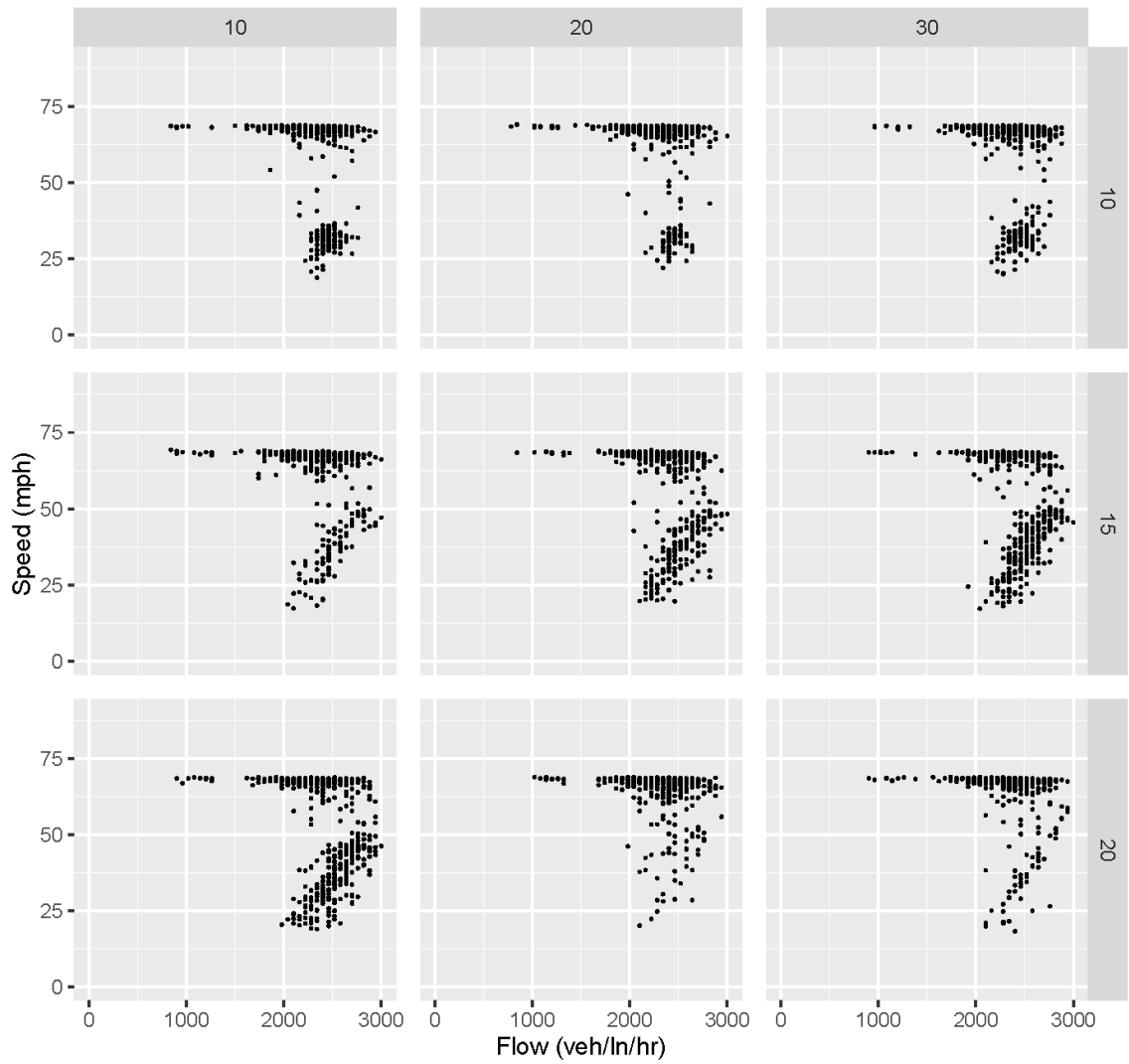


Figure 76: Speed-Flow Comparison Matrix for 2,000veh/ln at the LL Merge with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

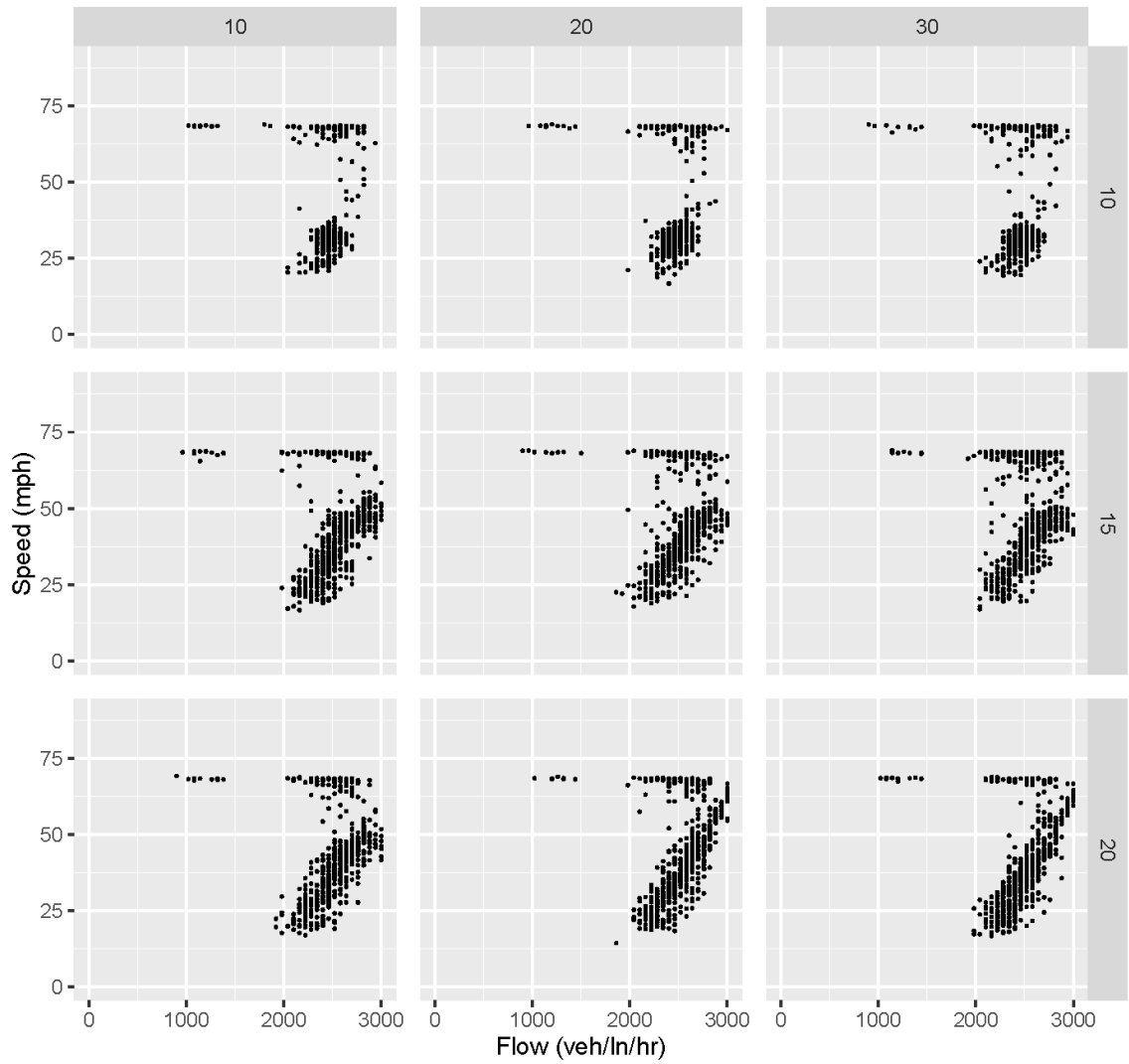


Figure 77: Speed-Flow Comparison Matrix for 2,200veh/ln at the LL.Merge with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

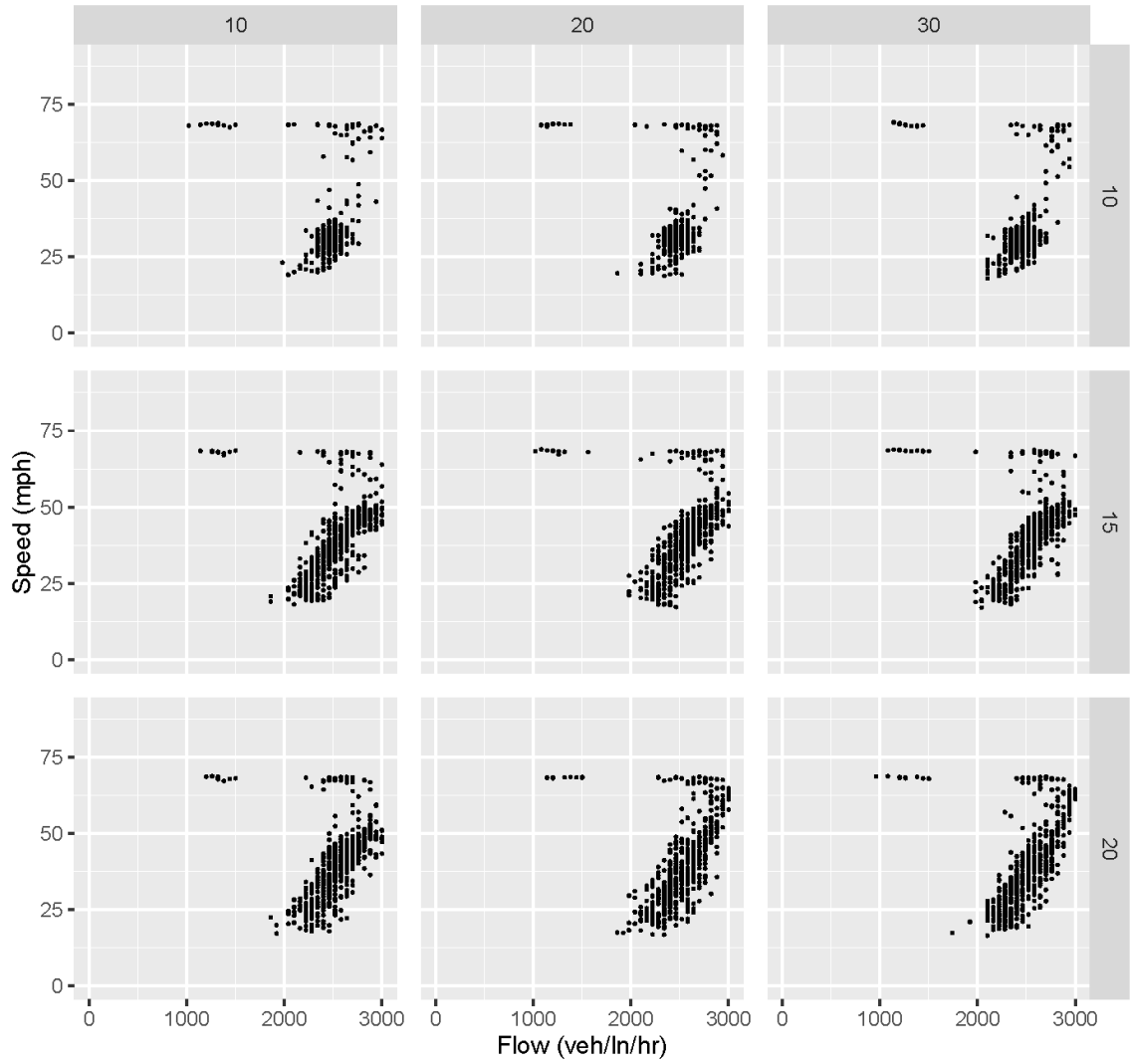


Figure 78: Speed-Flow Comparison Matrix for 2,400veh/ln at the LL Merge with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

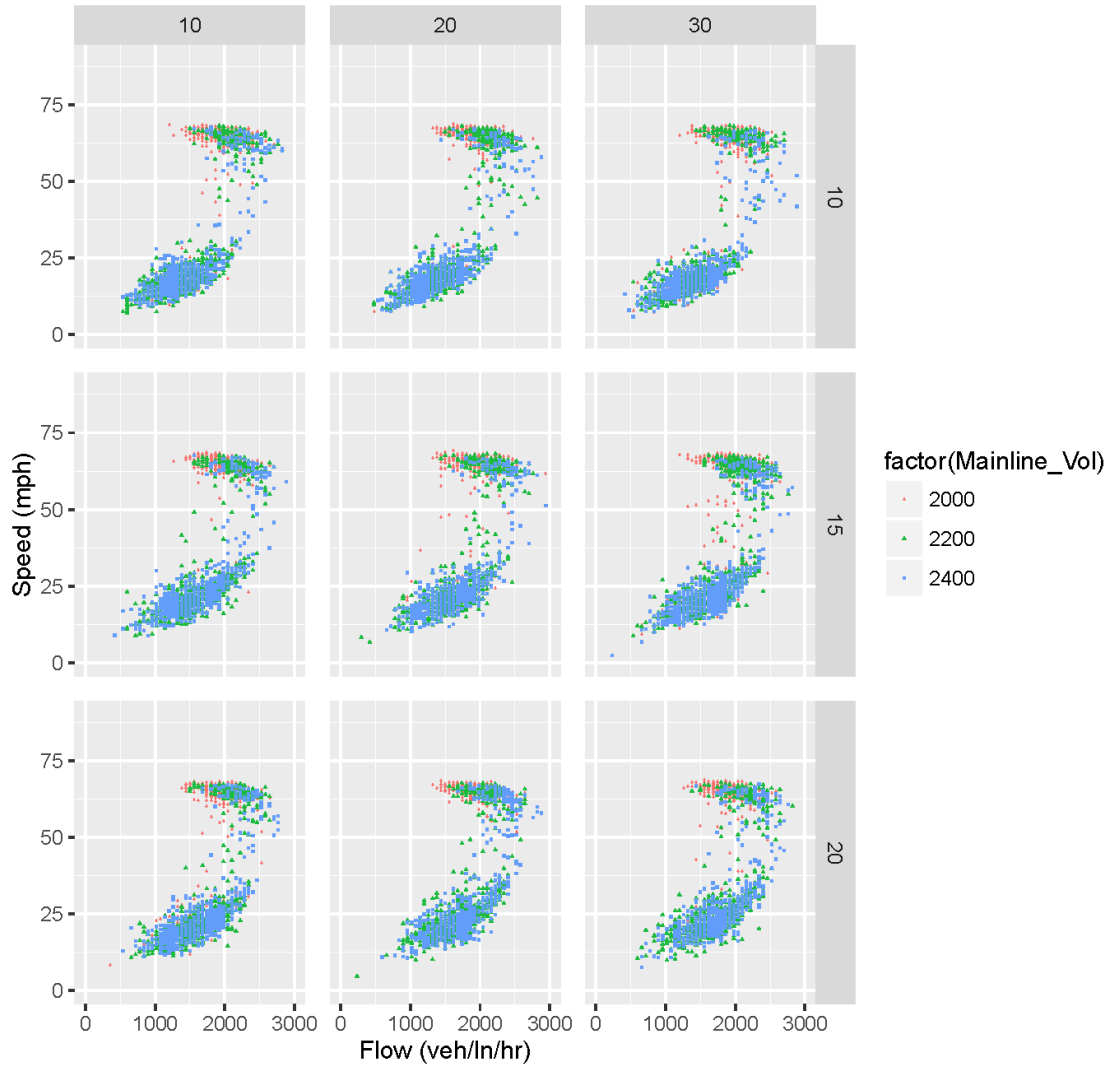


Figure 79: Speed-Flow Comparison Matrix for All Volumes at the RL.Enter with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

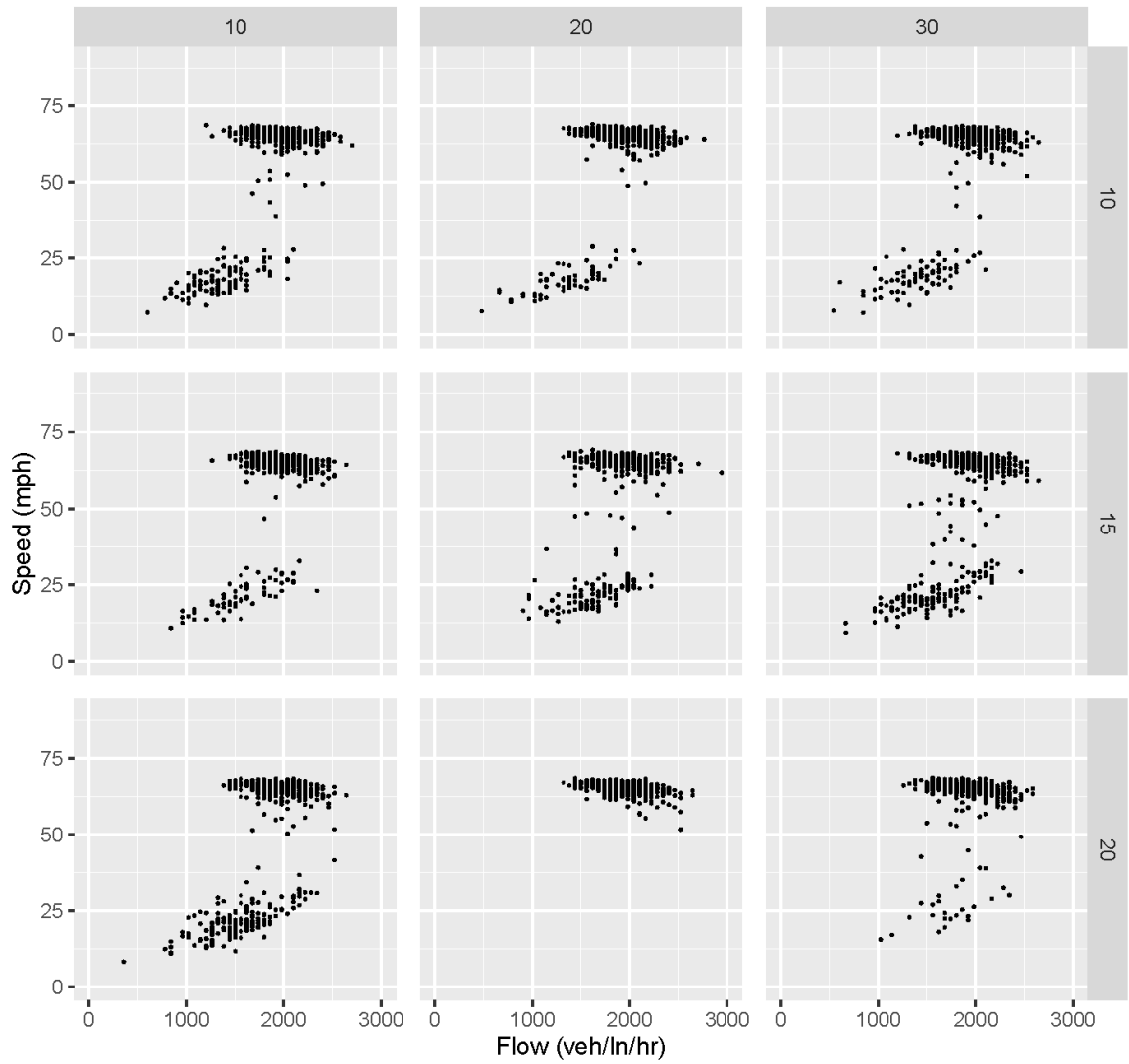


Figure 80: Speed-Flow Comparison Matrix for 2,000veh/ln at the RL.Enter with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

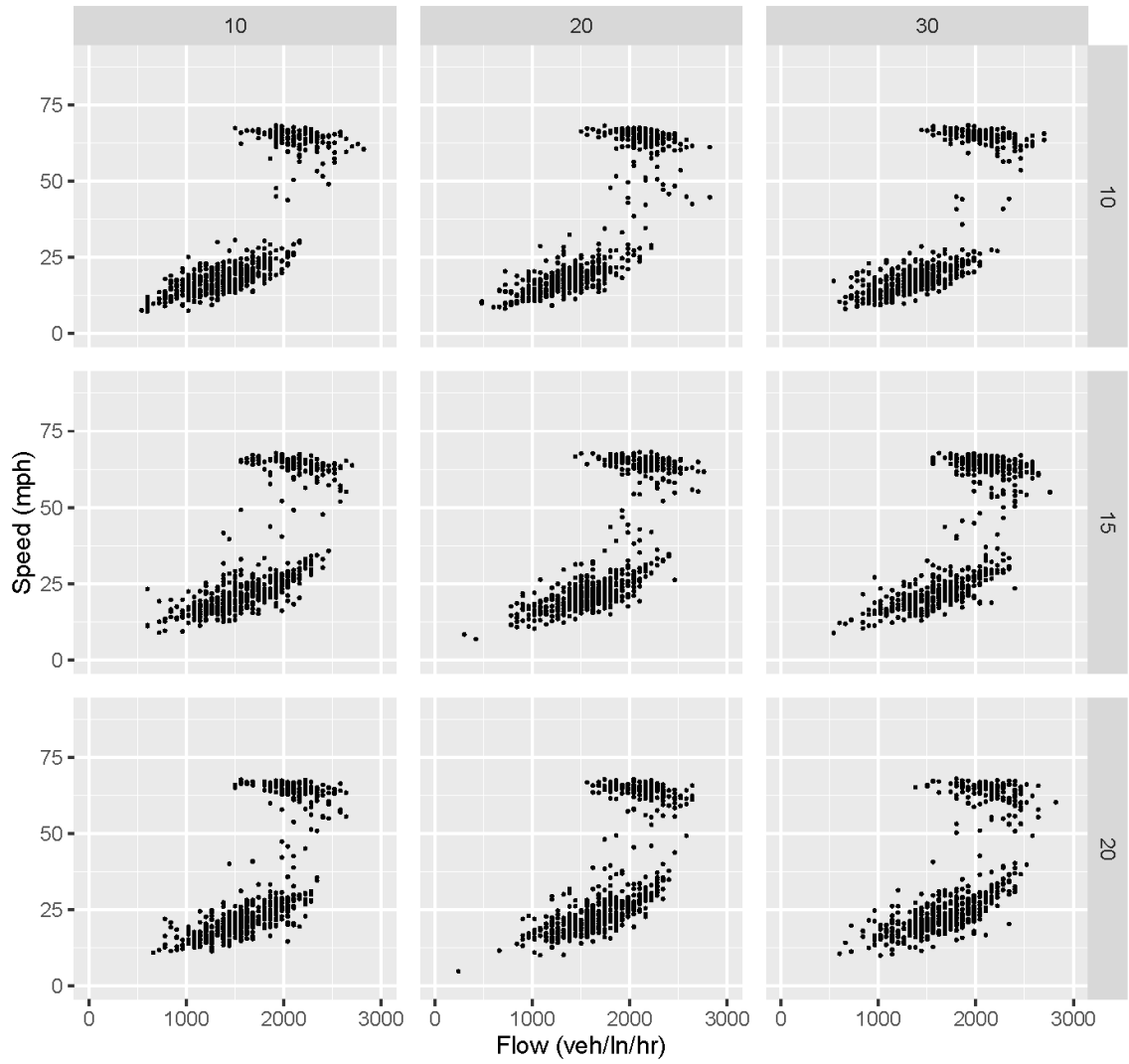


Figure 81: Speed-Flow Comparison Matrix for 2,200veh/ln at the RL.Enter with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

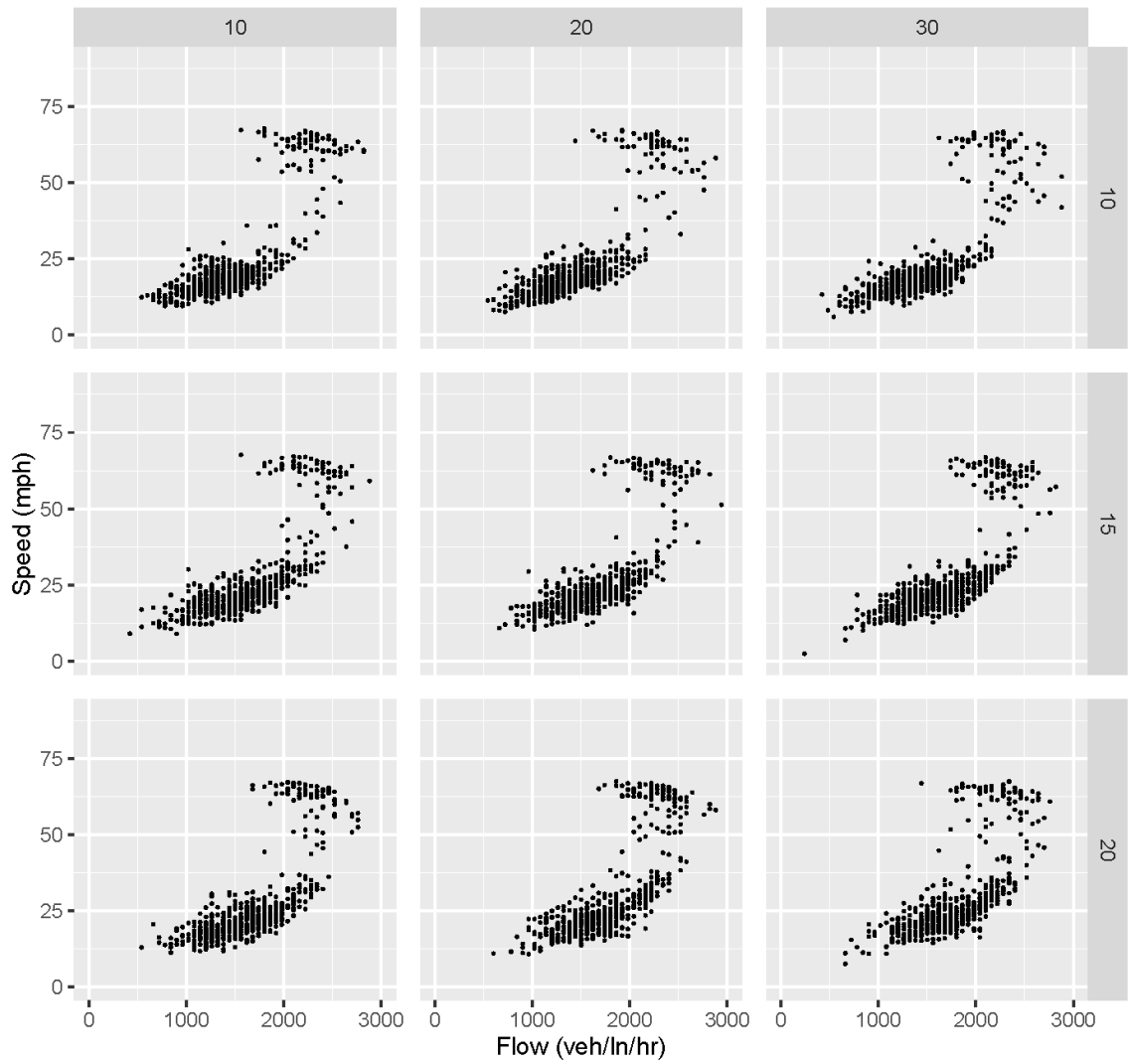


Figure 82: Speed-Flow Comparison Matrix for 2,400veh/ln at the RL.Enter with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

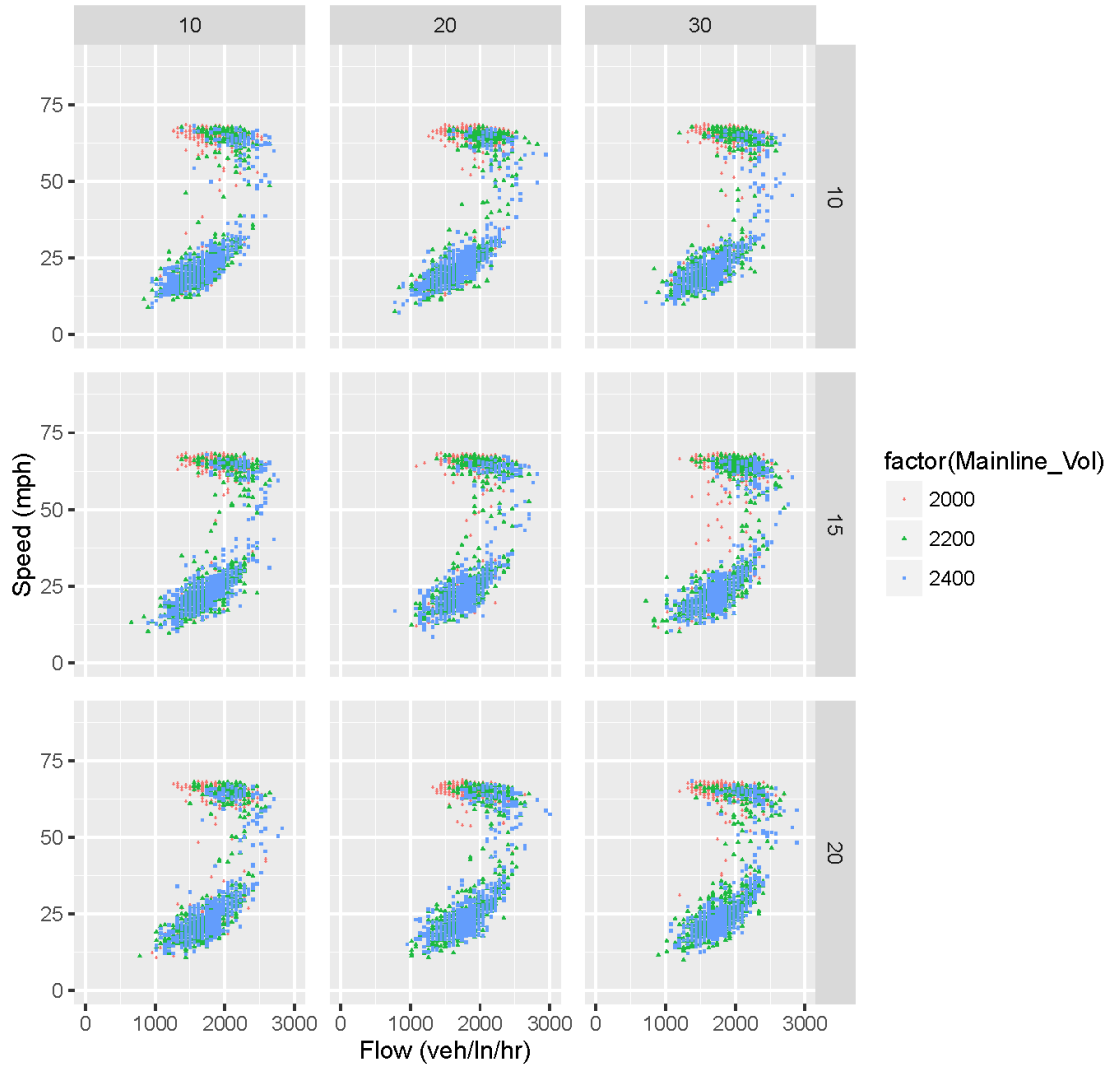


Figure 83: Speed-Flow Comparison Matrix for All Volumes at the CL.Enter with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

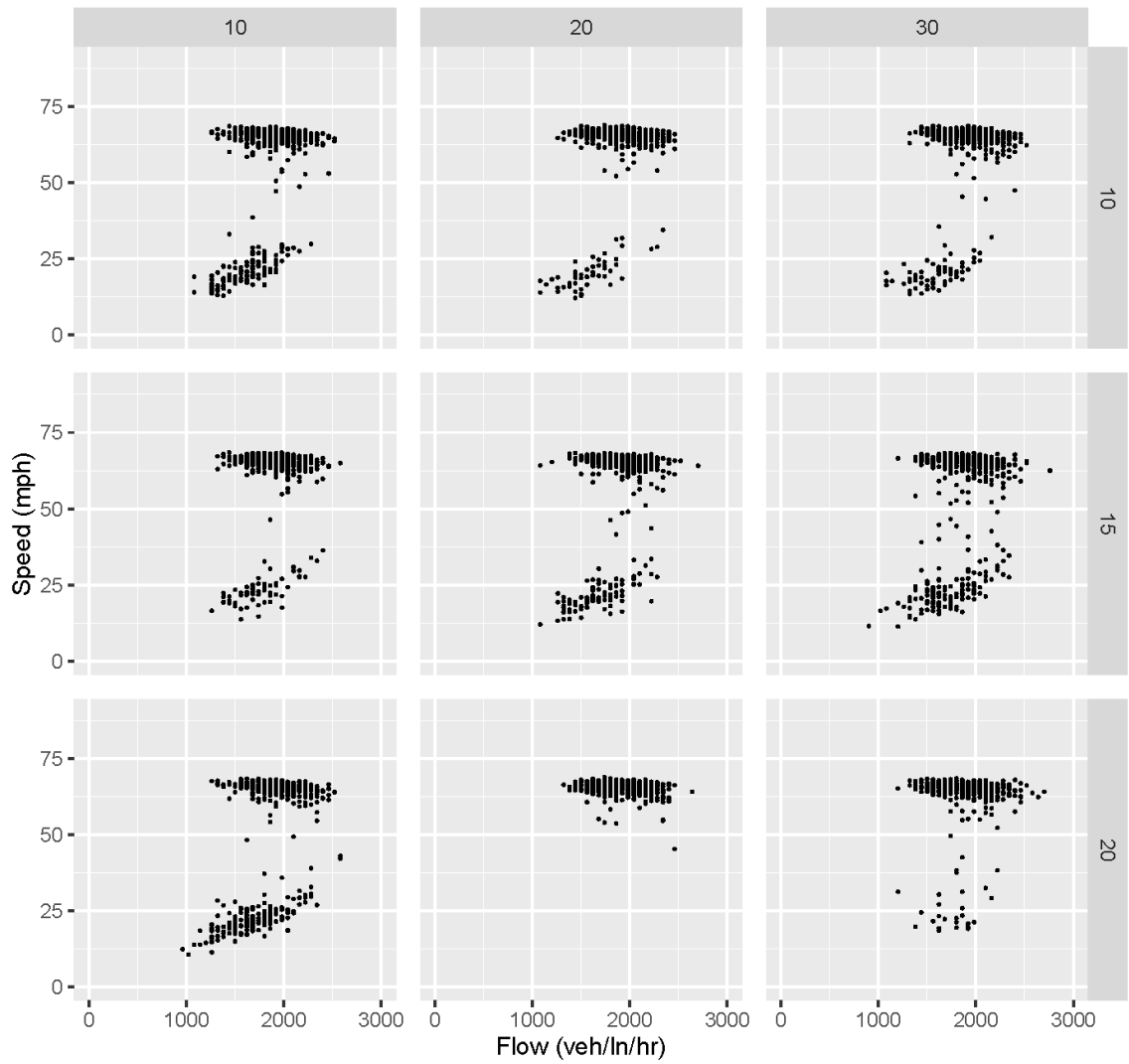


Figure 84: Speed-Flow Comparison Matrix for 2,000veh/ln at the CL.Enter with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

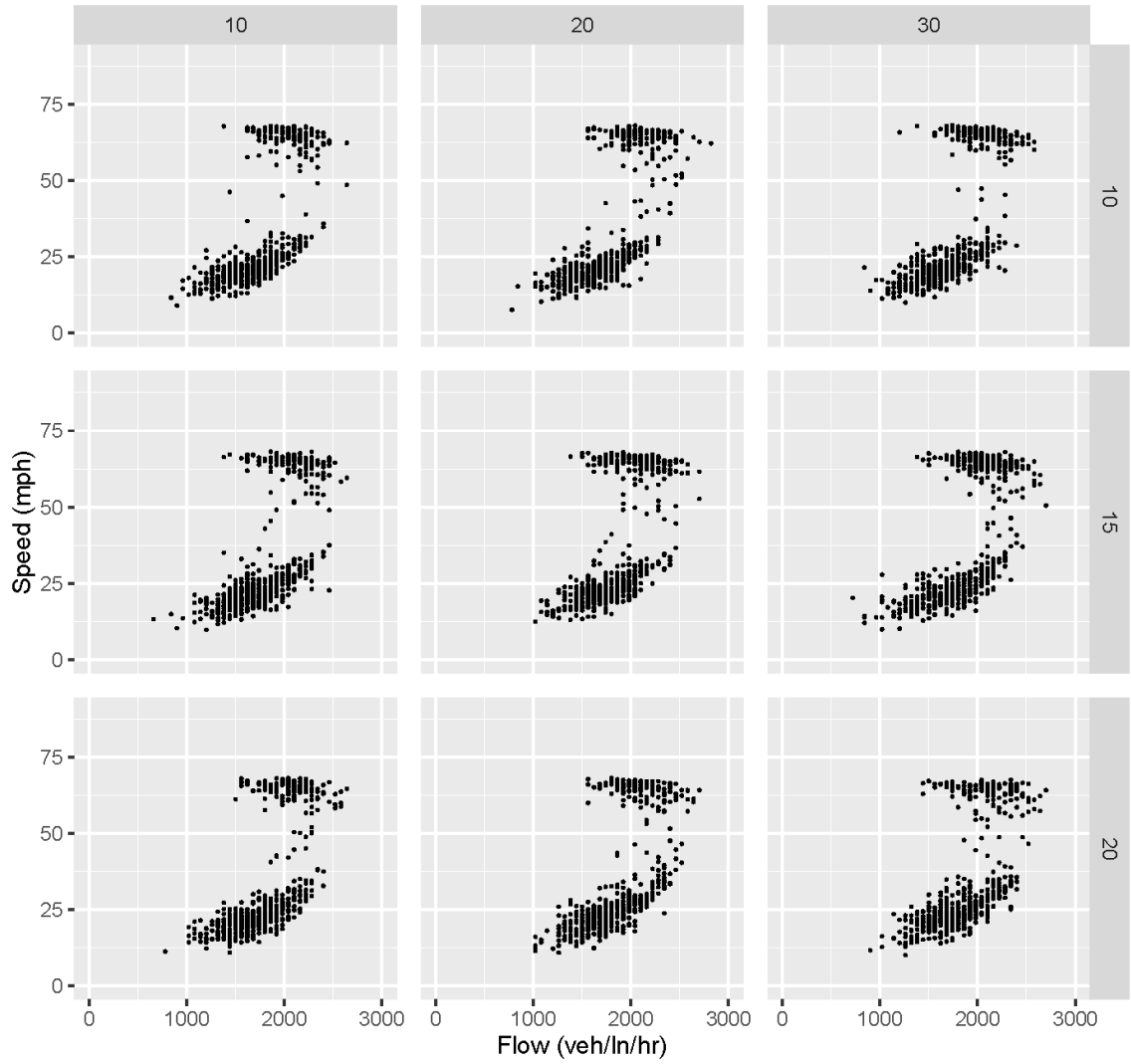


Figure 85: Speed-Flow Comparison Matrix for 2,200veh/ln at the CL.Enter with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

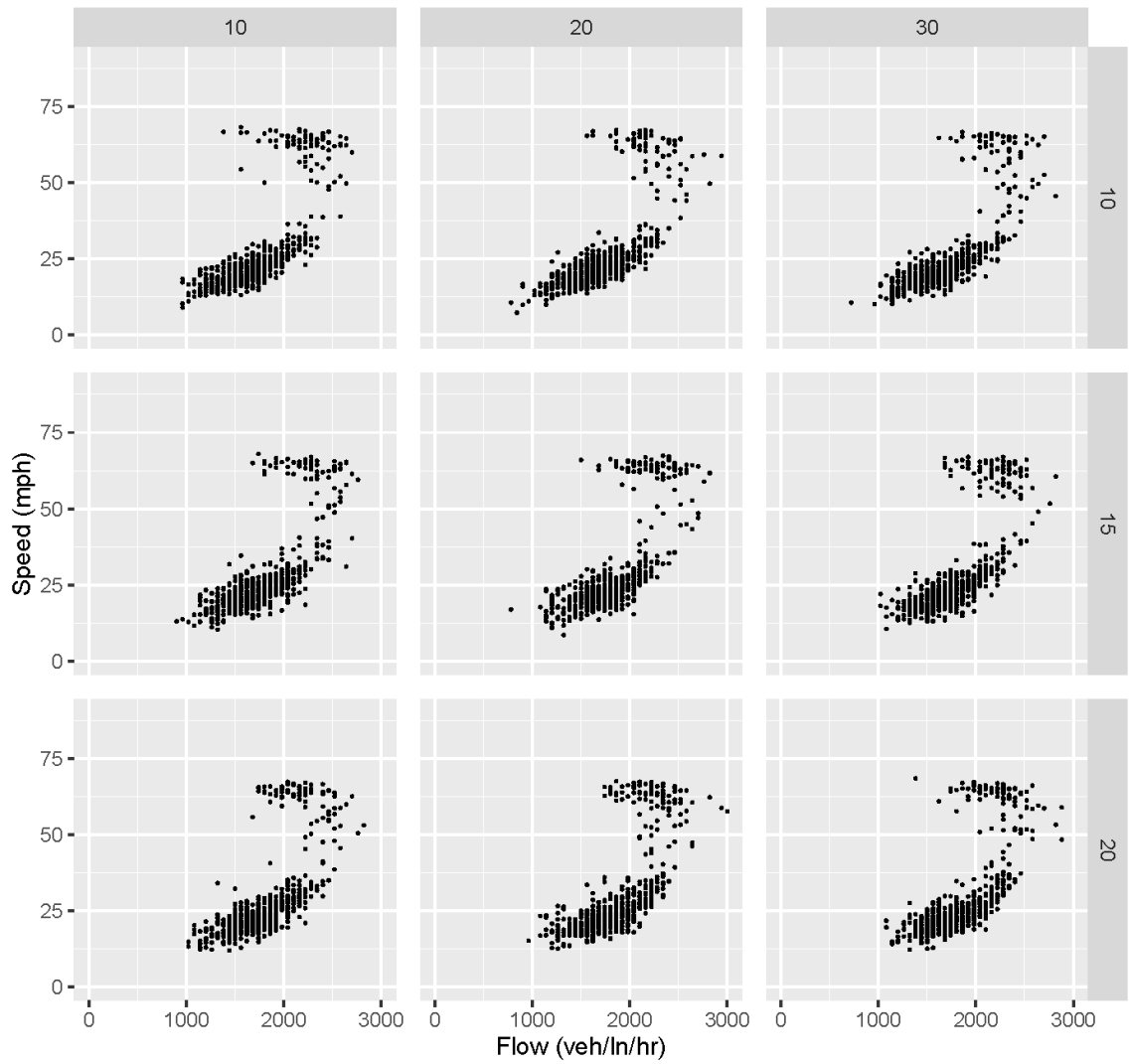


Figure 86: Speed-Flow Comparison Matrix for 2,400veh/ln at the CL.Enter with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

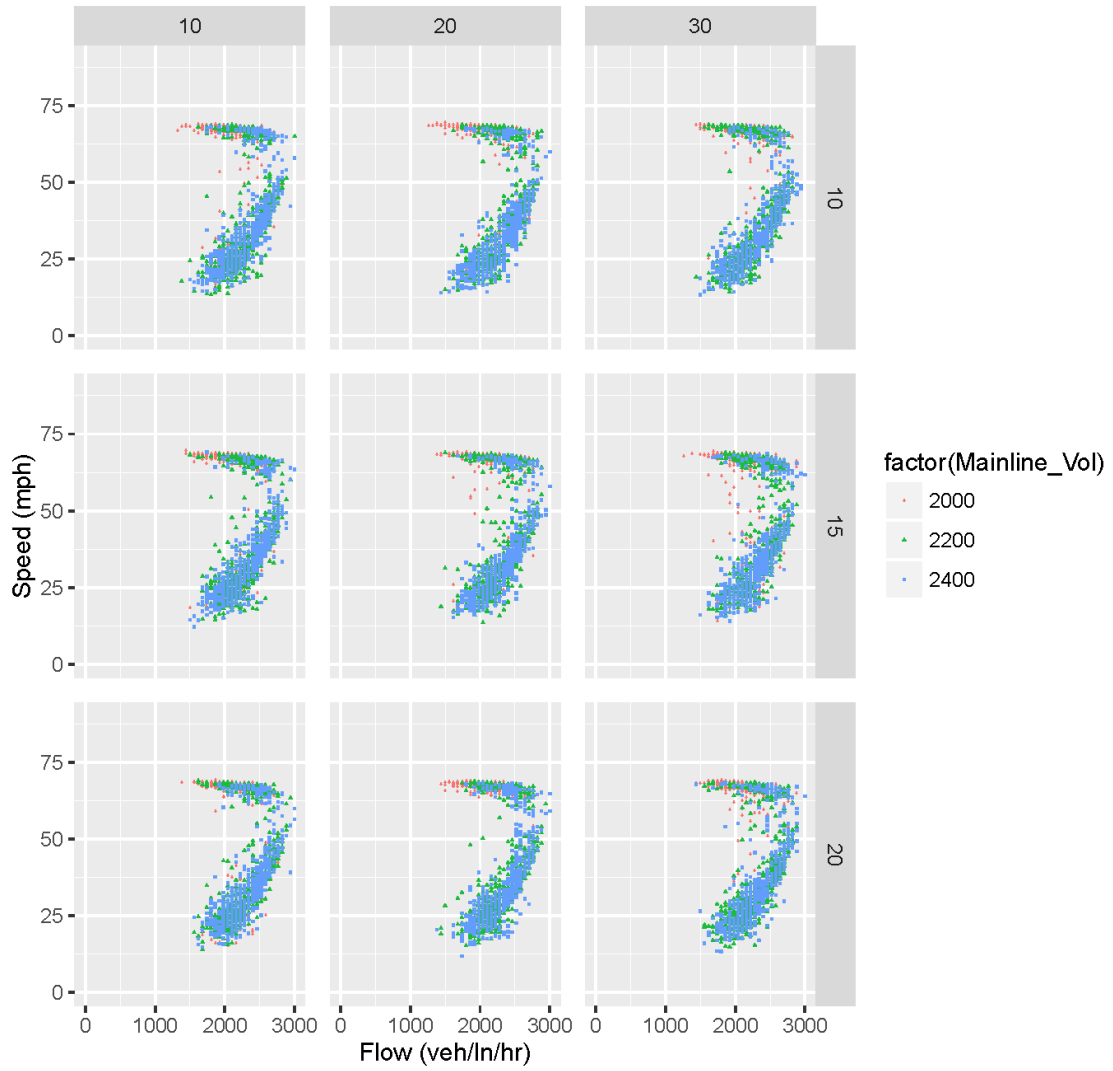


Figure 87: Speed-Flow Comparison Matrix for All Volumes at the LL.Enter with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

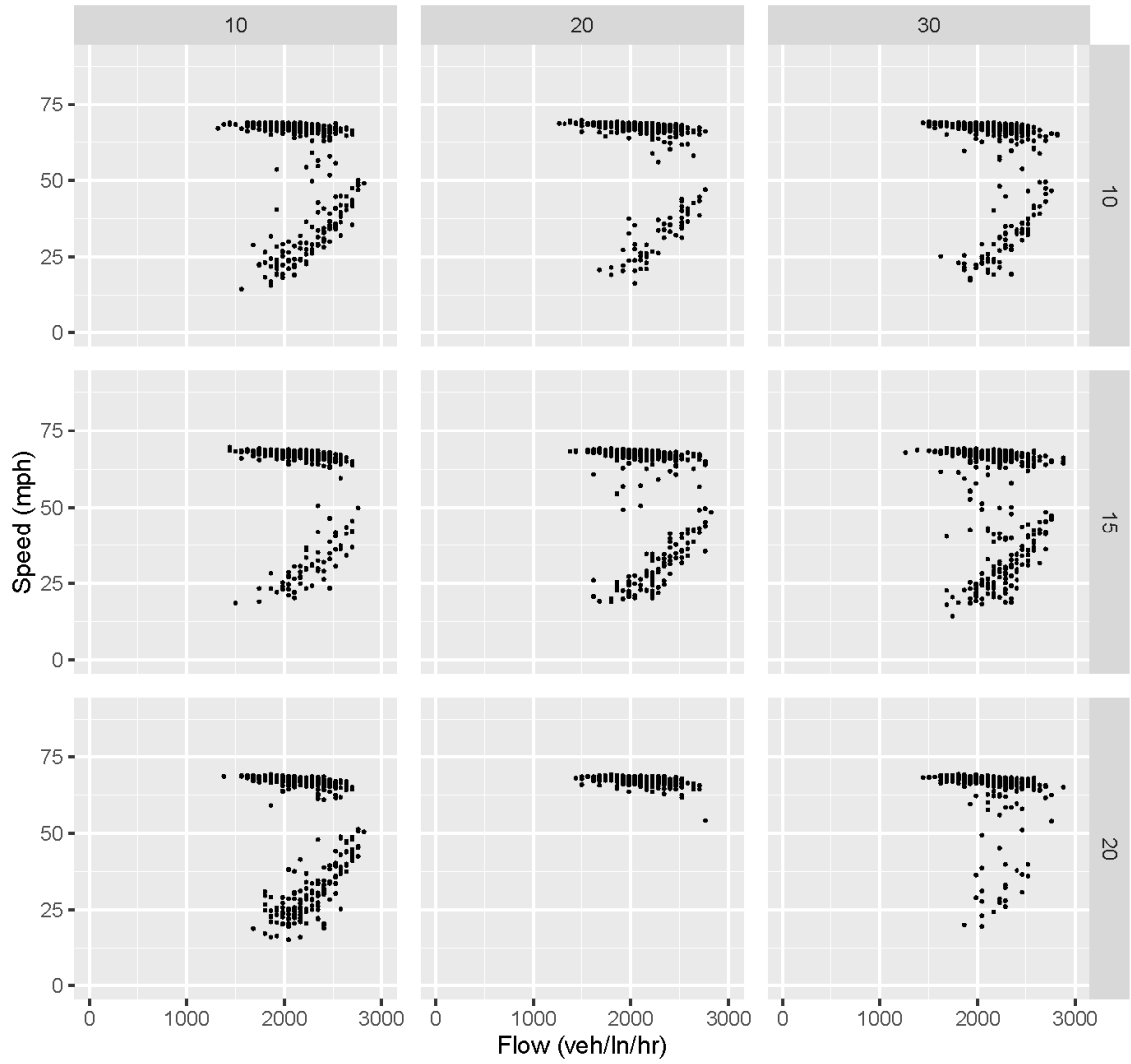


Figure 88: Speed-Flow Comparison Matrix for 2,000veh/ln at the LL.Enter with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

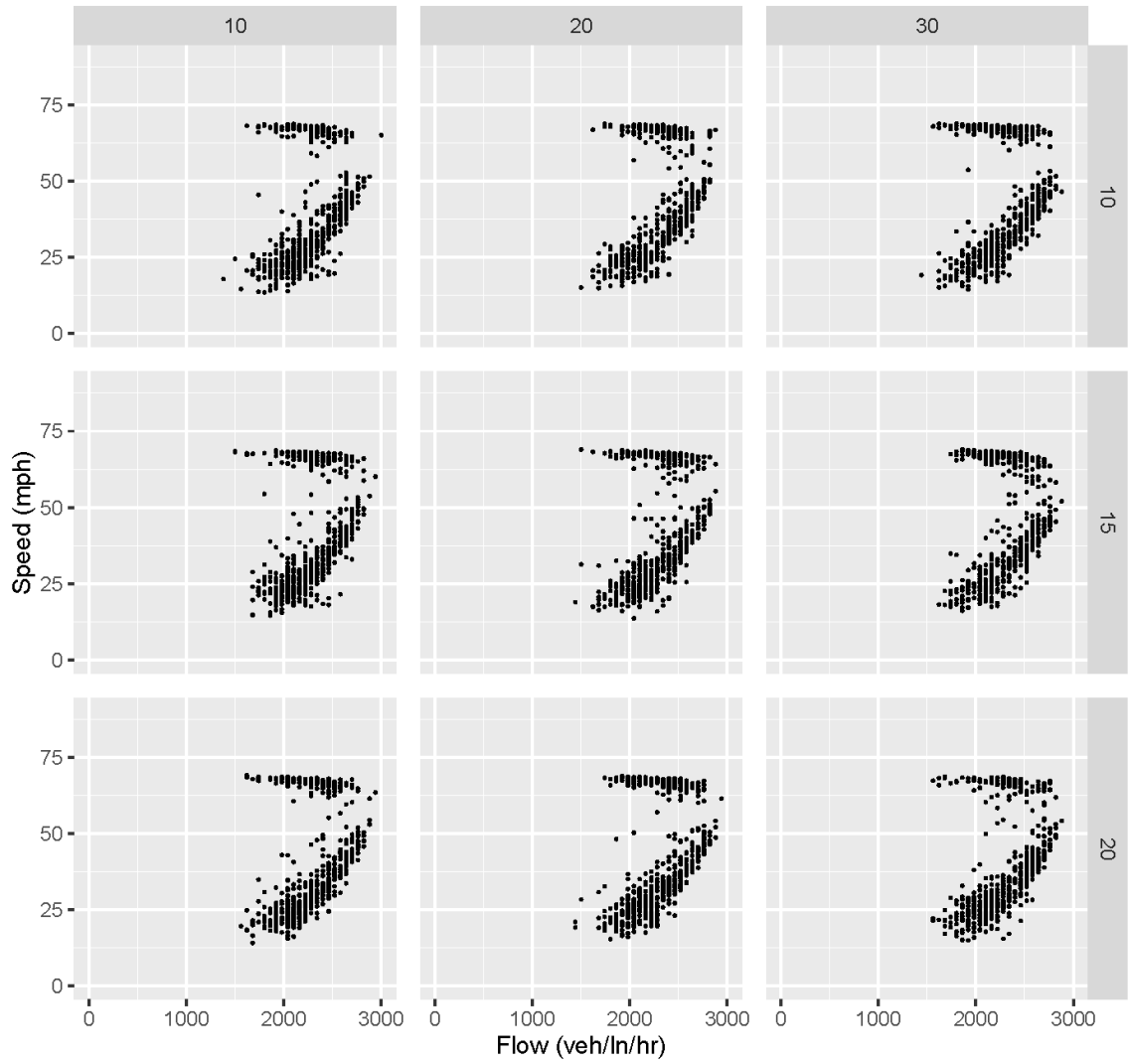


Figure 89: Speed-Flow Comparison Matrix for 2,200veh/ln at the LL.Enter with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

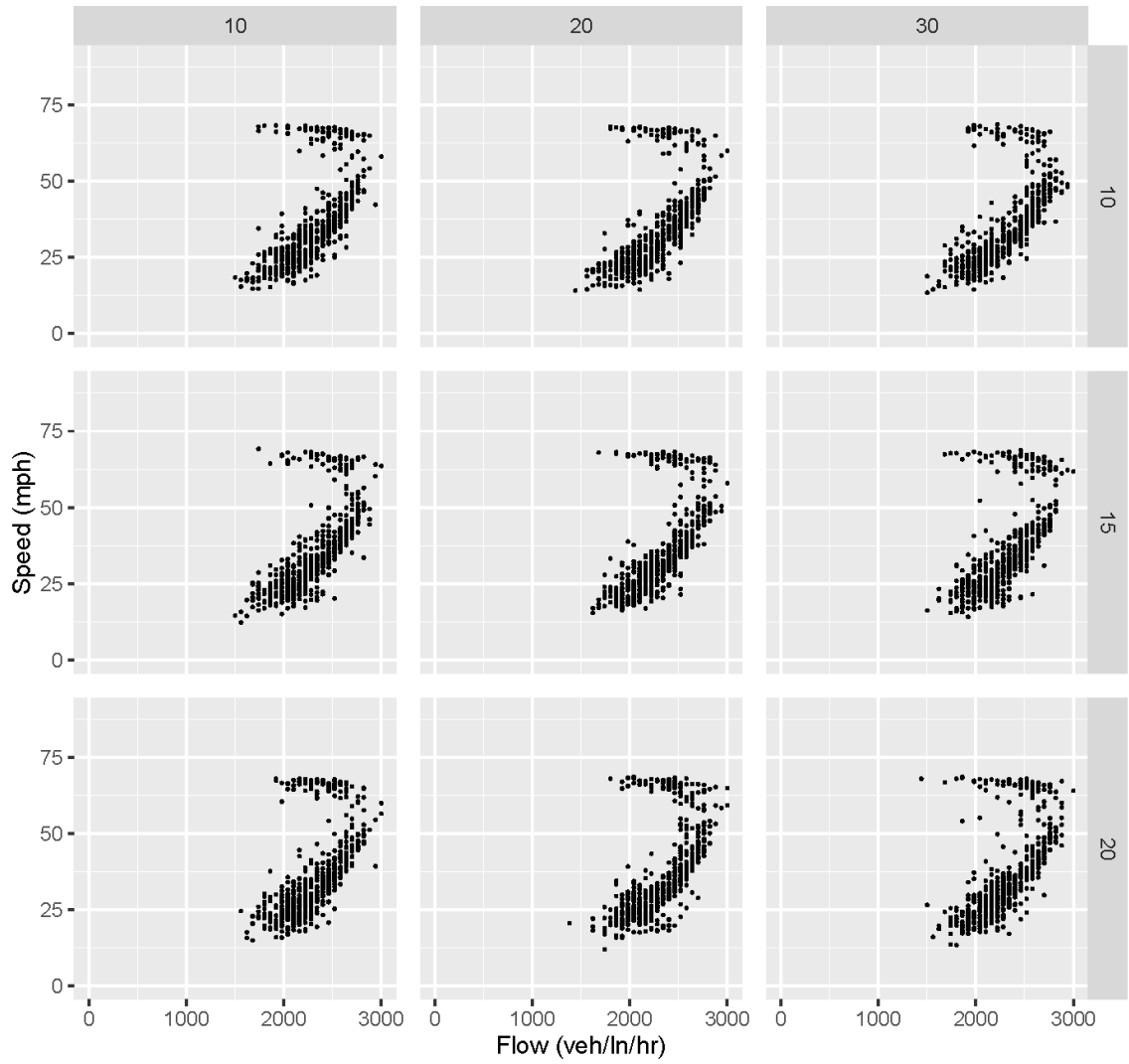


Figure 90: Speed-Flow Comparison Matrix for 2,400veh/ln at the LL.Enter with Varying Thresholds and Speed Increments (On-Ramp: 1,000vehs)

APPENDIX F

ADDITIONAL NON-RAMP METERED AND RAMP METERED CASE COMPARISON MATRICES AND BAR PLOTS

The additional speed-flow comparison matrices within Appendix E have been ordered as follows: CL.Merge, LL.Merge, RL.Enter, CL.Enter and LL.Enter. The first figure for each data collection point will be of all the data points plotted followed by three more figures with each mainline volume plotted individually. Additionally, comparison bar plots of the entering and exiting flows for the 2,000veh/ln and 2,400veh/ln mainline volumes follow the speed-flow comparison matrices.

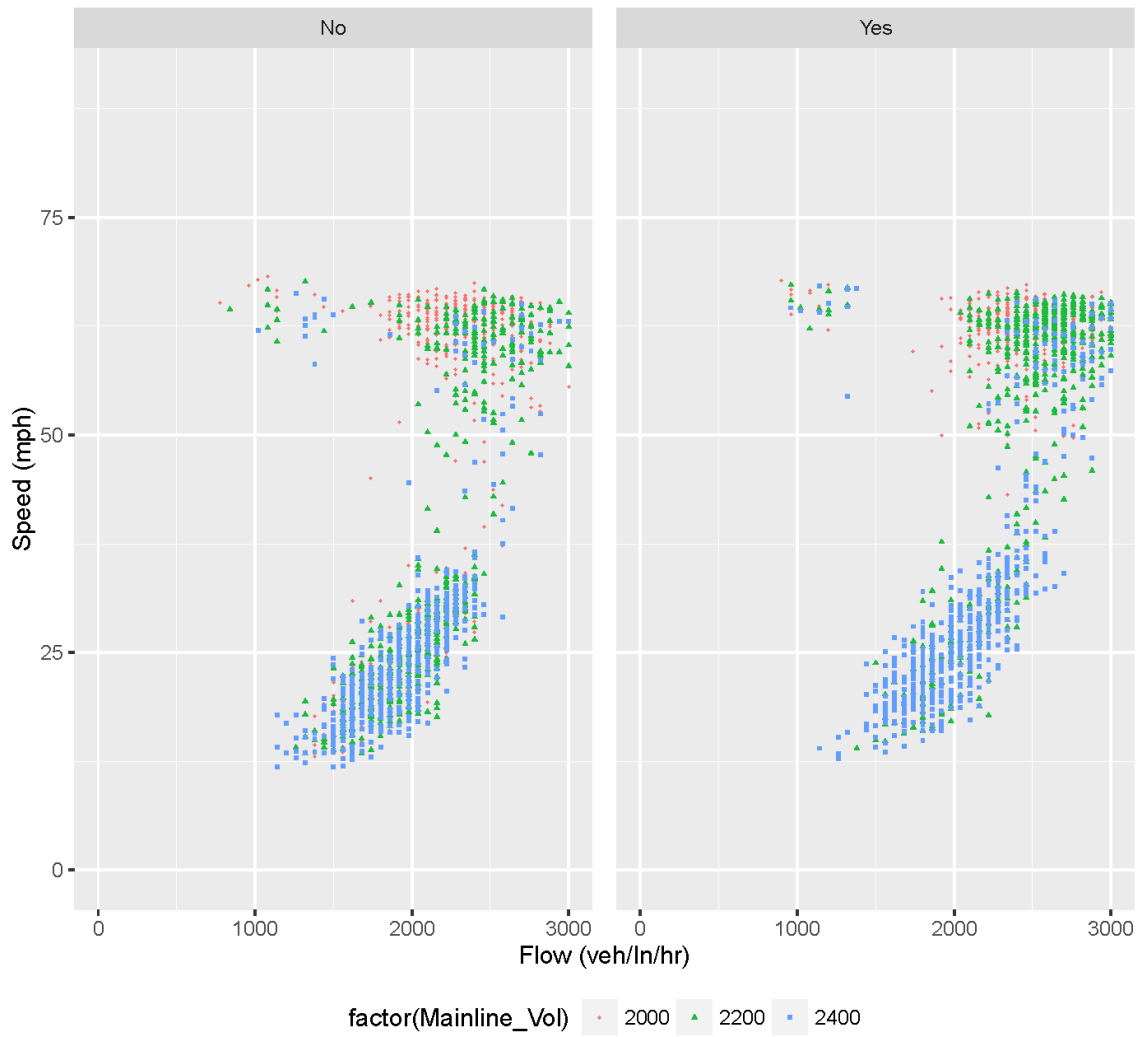


Figure 91: Comparison of Non-Ramp Metered and Ramp Metered Case for All Data at the CL.Merge (On-Ramp: 1,000vehs)

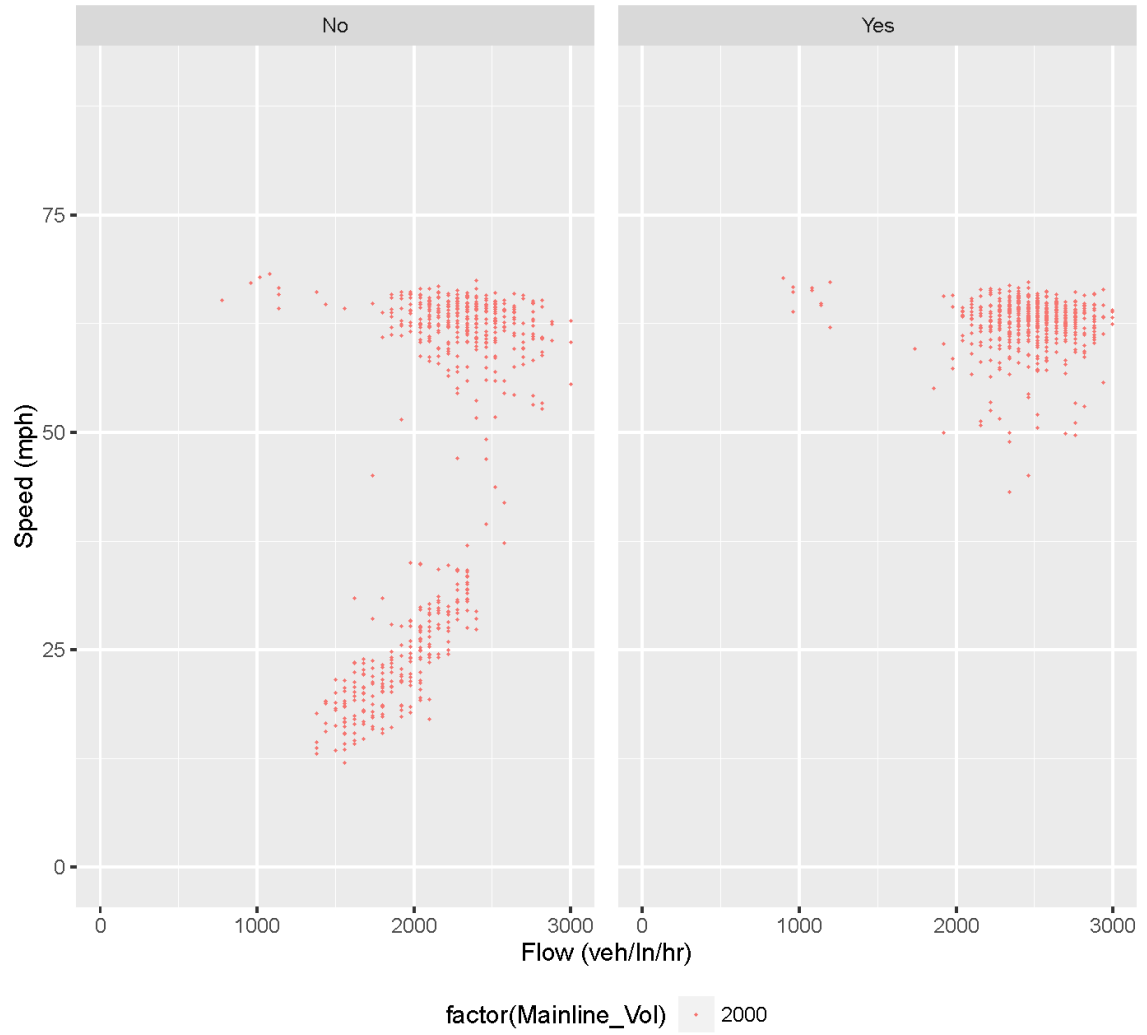


Figure 92: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,000veh/ln at the CL.Merge (On-Ramp: 1,000vehs)

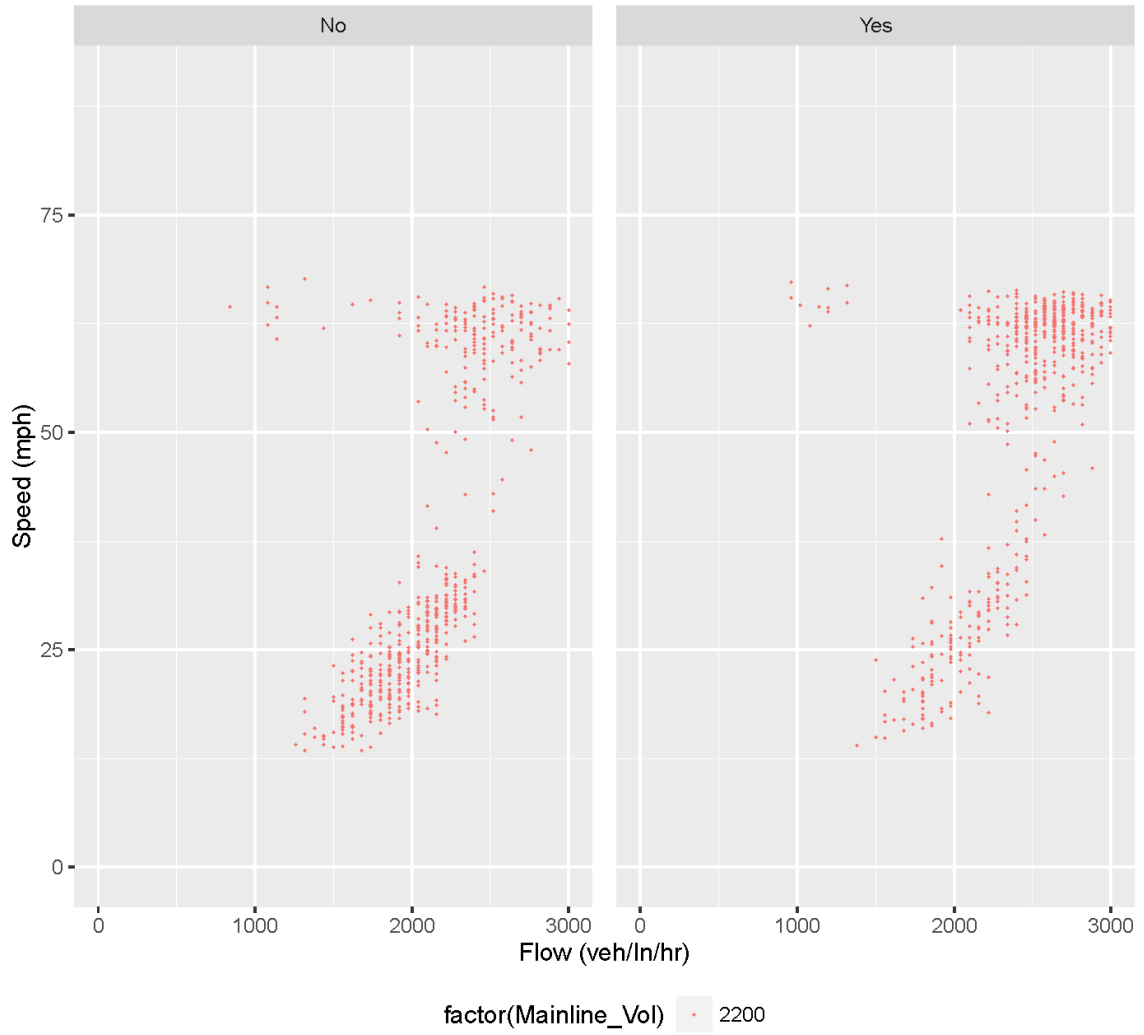


Figure 93: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,200veh/ln at the CL.Merge (On-Ramp: 1,000vehs)

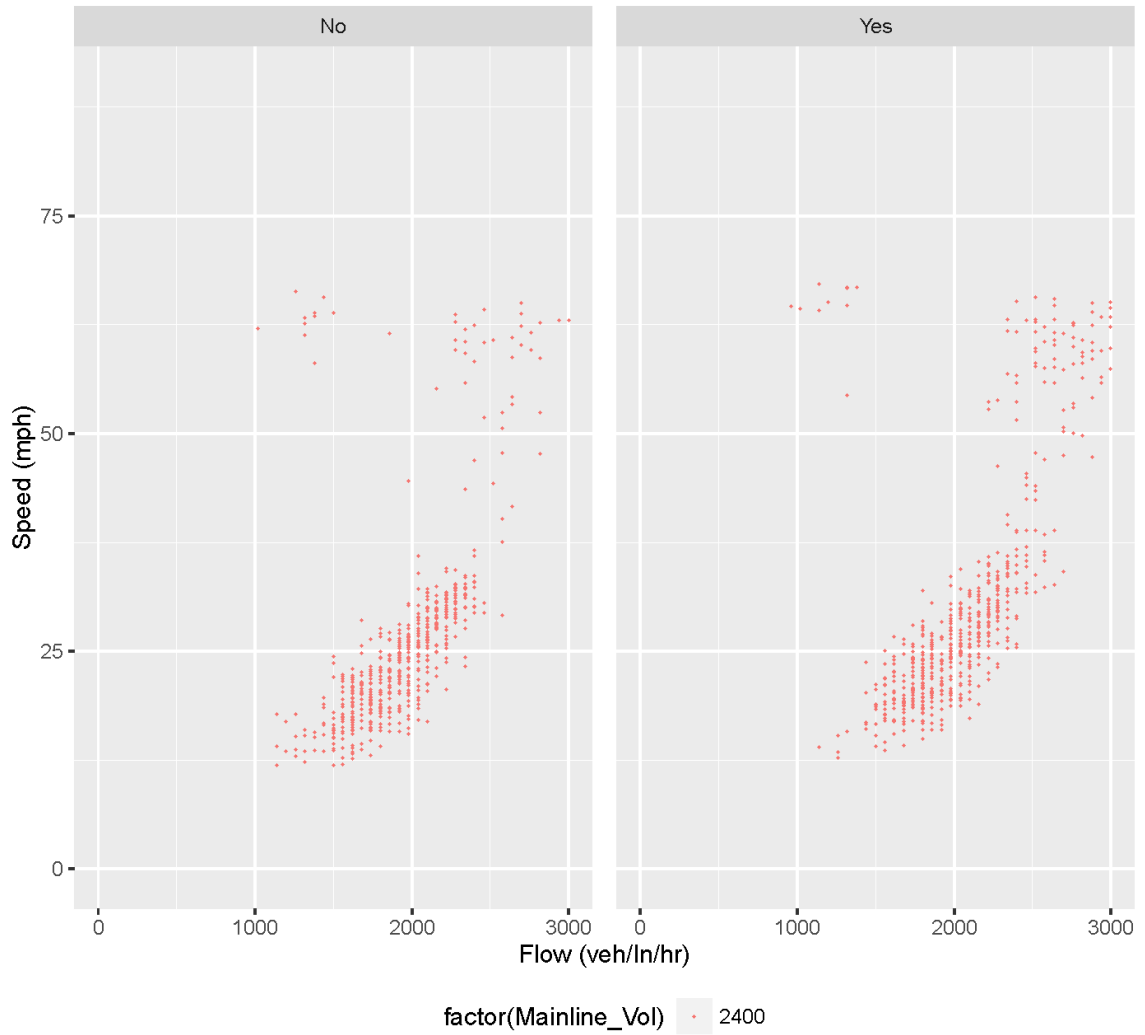


Figure 94: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,400veh/ln at the CL.Merge (On-Ramp: 1,000vehs)

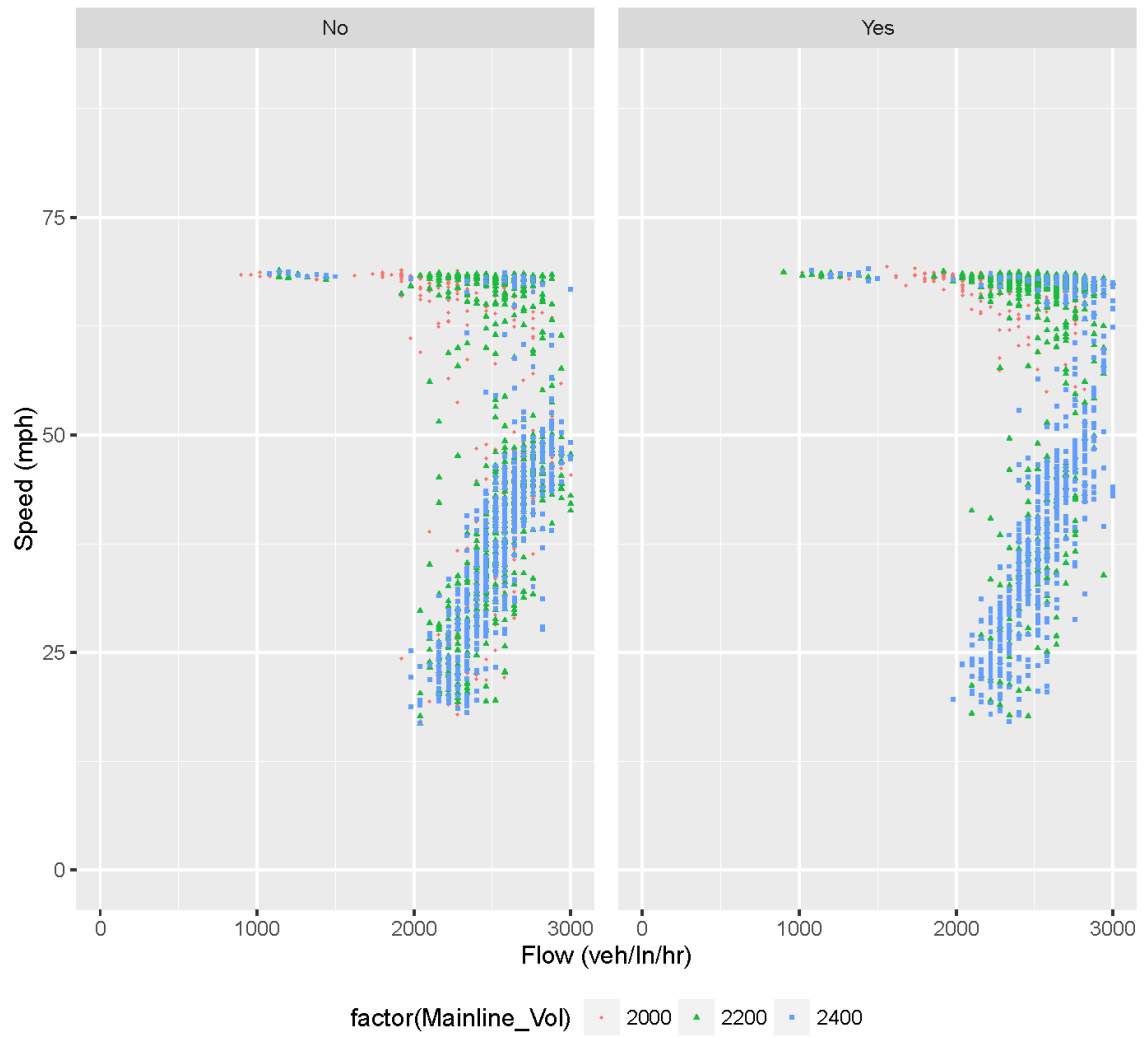


Figure 95: Comparison of Non-Ramp Metered and Ramp Metered Case for All Volumes at the LLMerge (On-Ramp: 1,000vehs)

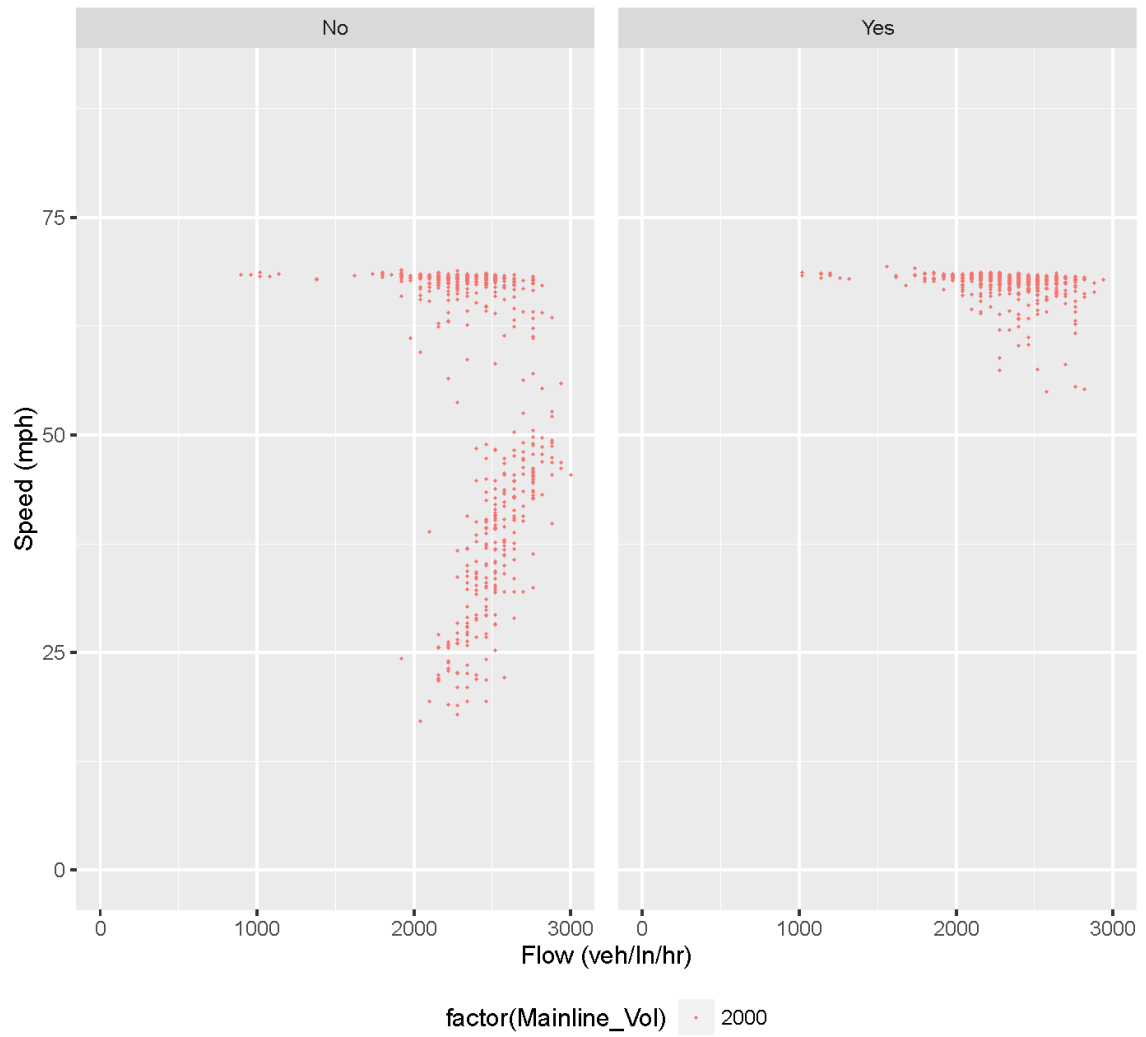


Figure 96: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,000veh/ln at the LL.Merge (On-Ramp: 1,000vehs)

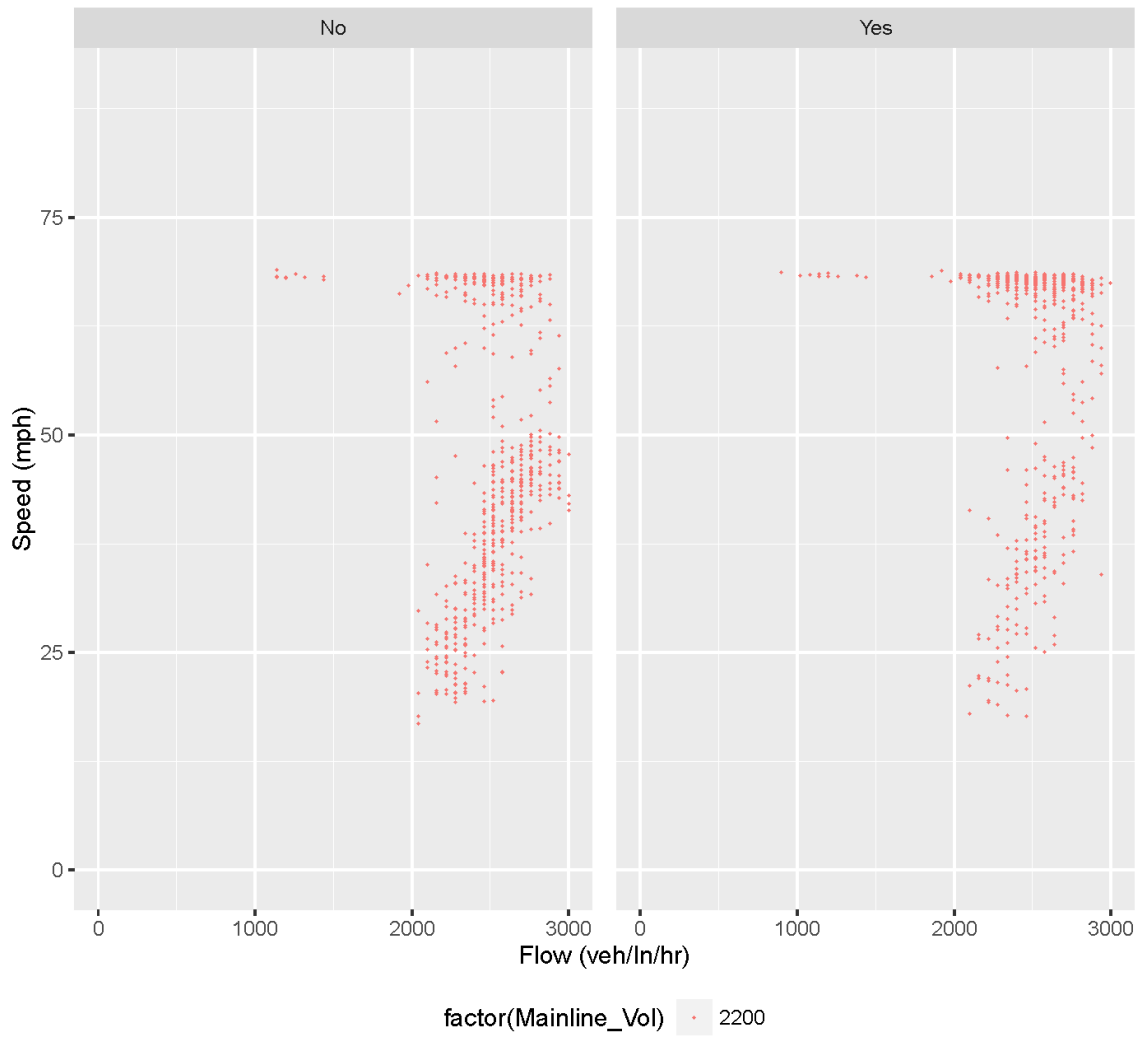


Figure 97: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,200veh/ln at the LL.Merge (On-Ramp: 1,000vehs)

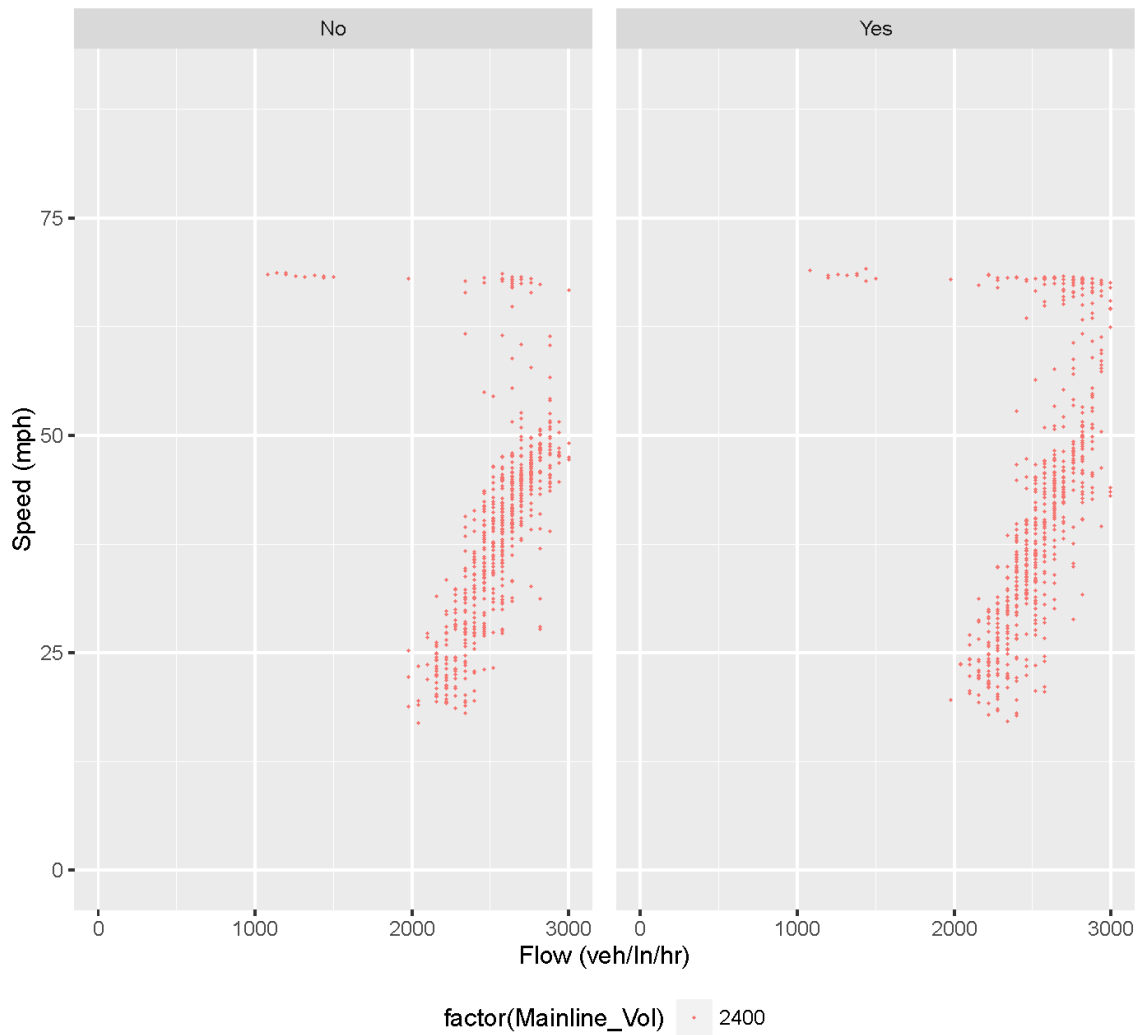


Figure 98: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,400veh/ln at the LL.Merge (On-Ramp: 1,000vehs)

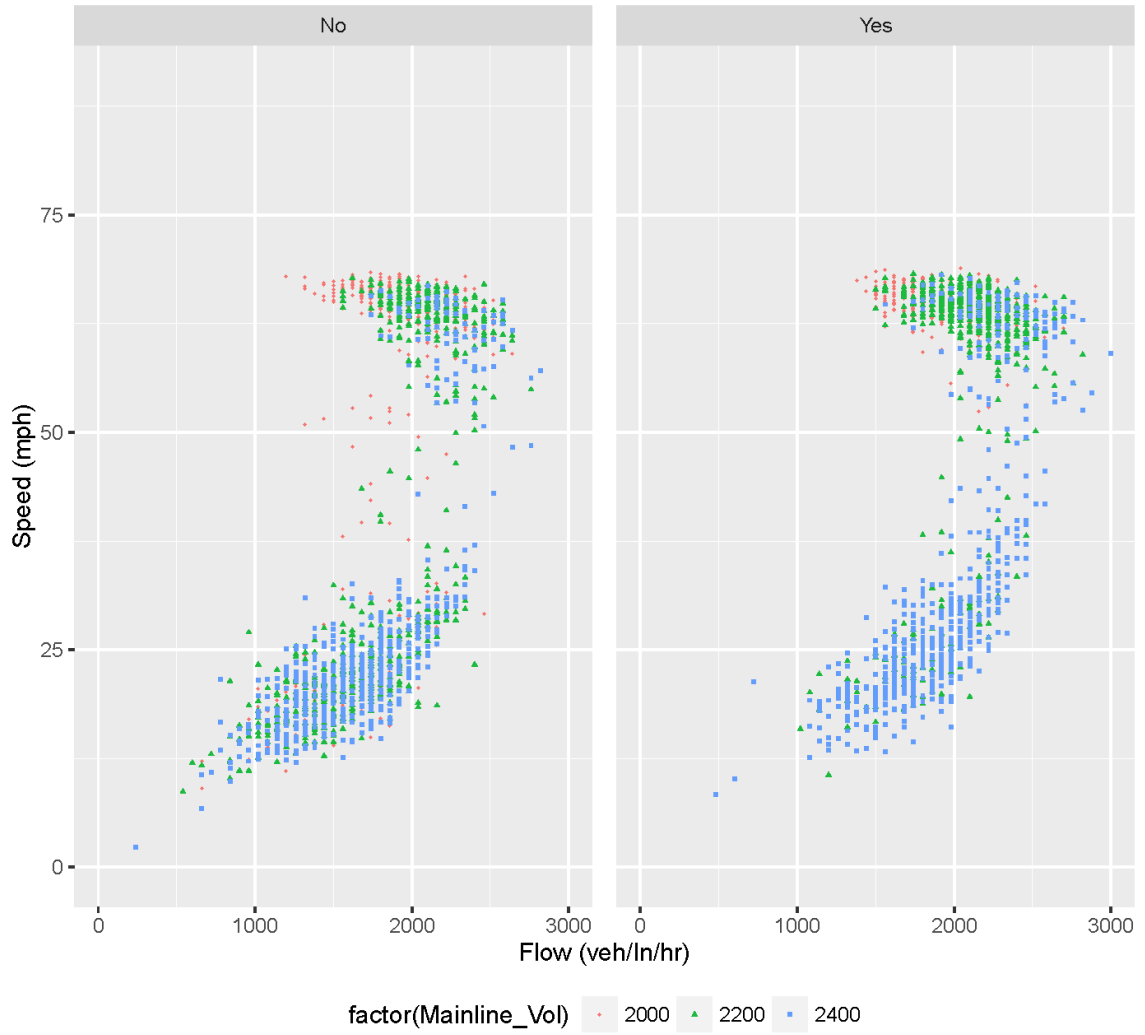


Figure 99: Comparison of Non-Ramp Metered and Ramp Metered Case for All Volumes at the RL.Enter (On-Ramp: 1,000vehs)

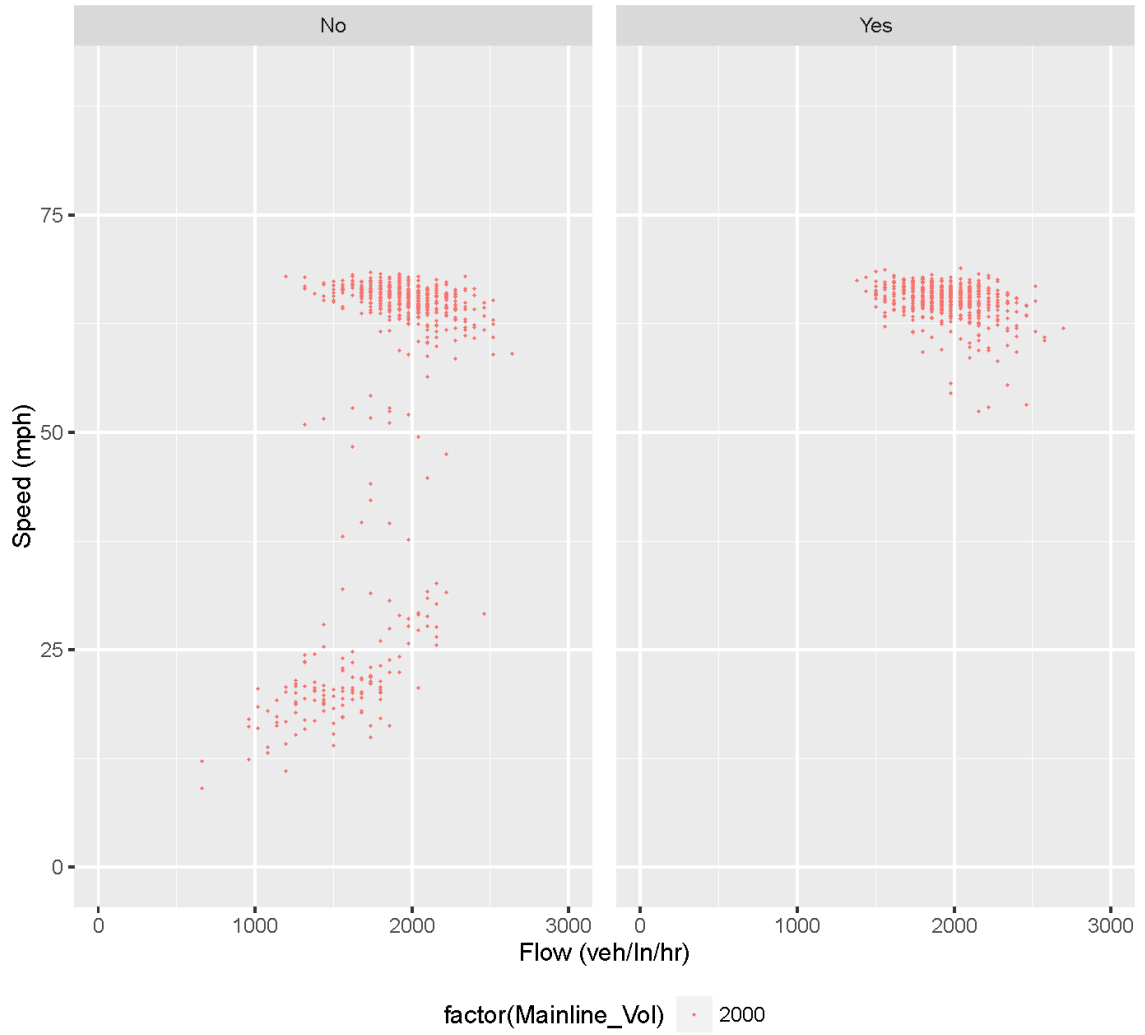


Figure 100: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,000veh/ln at the RL.Enter (On-Ramp: 1,000vehs)

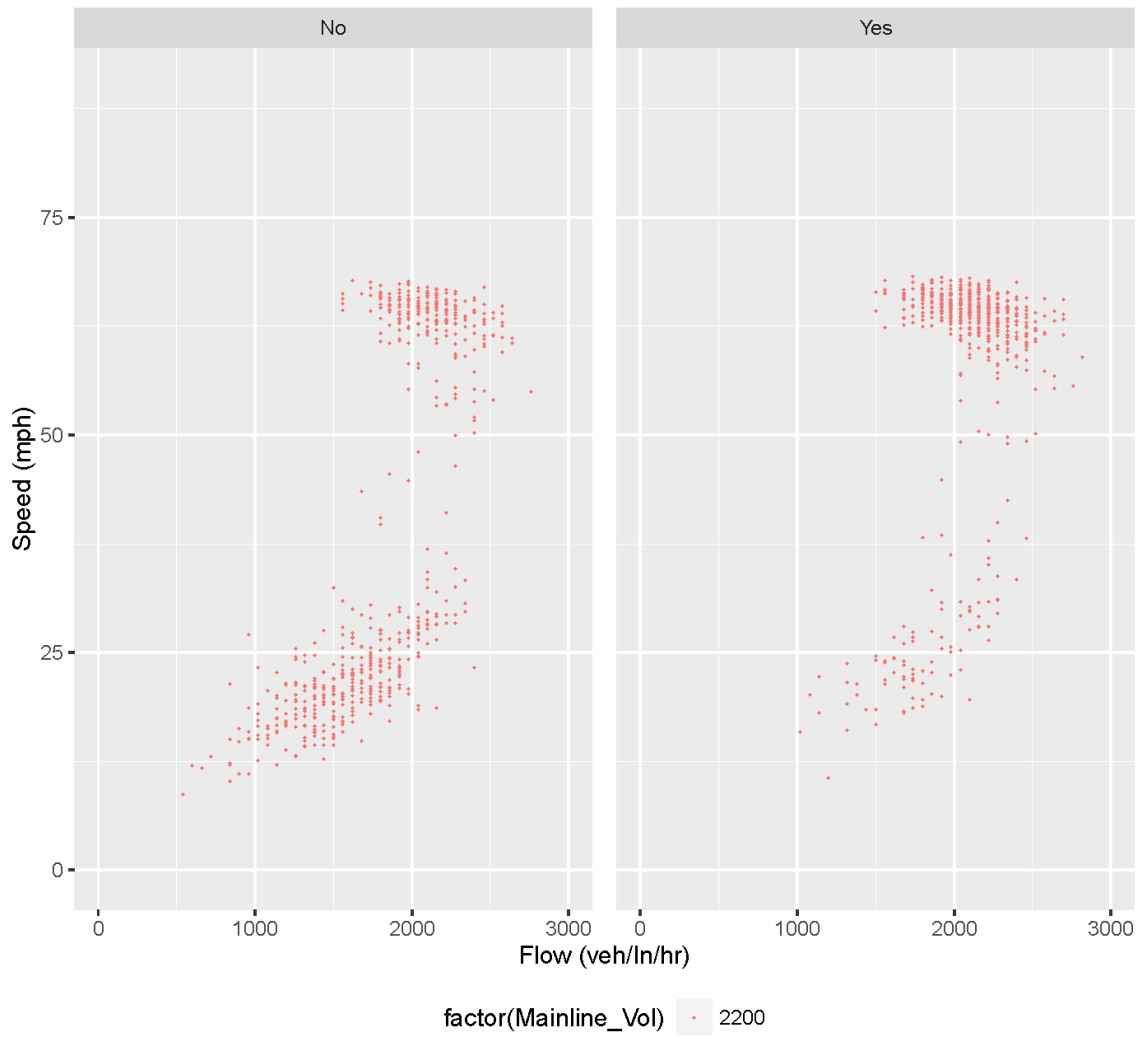


Figure 101: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,200veh/ln at the RL.Enter (On-Ramp: 1,000vehs)

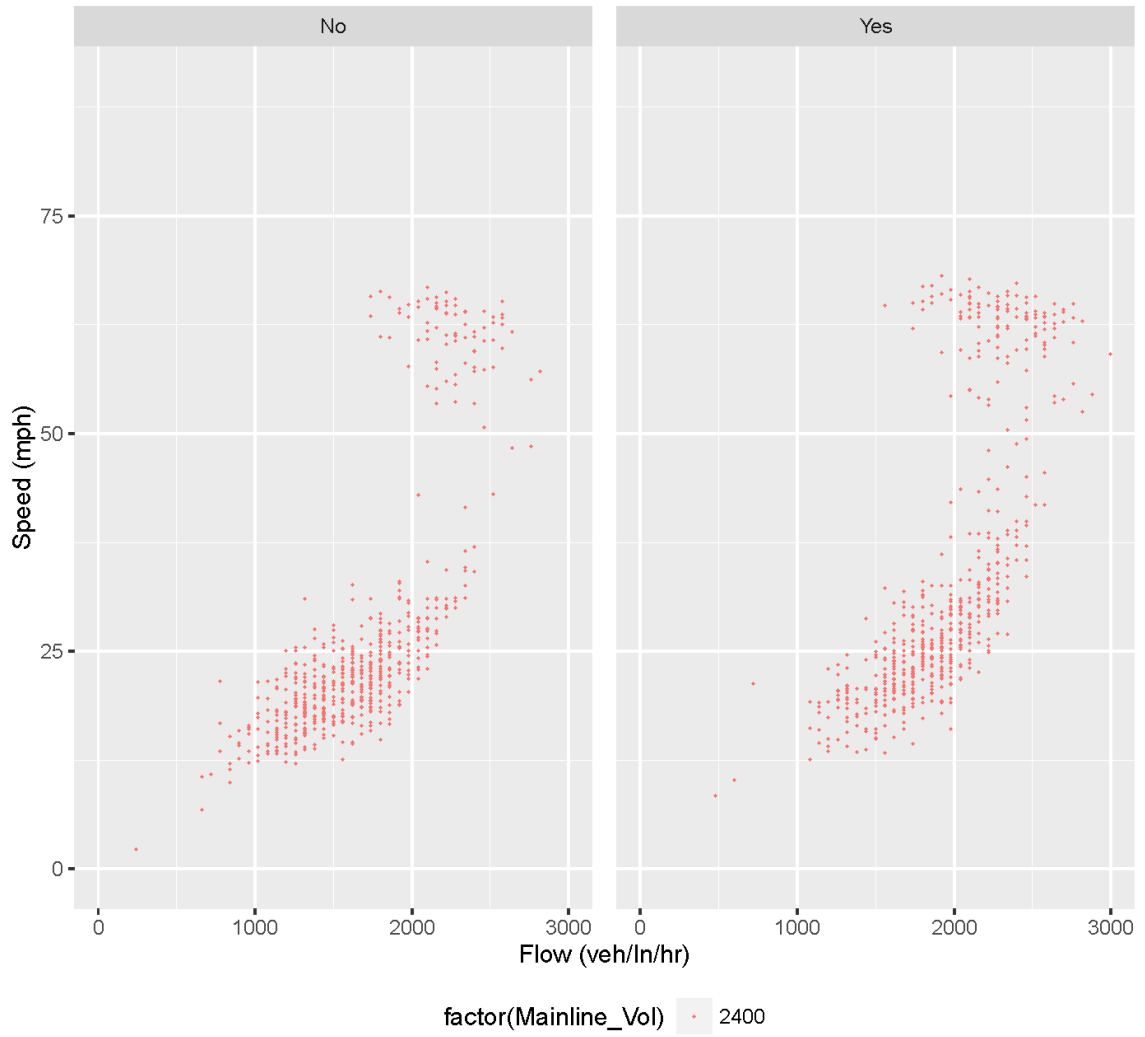


Figure 102: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,400veh/ln at the RL.Enter (On-Ramp: 1,000vehs)

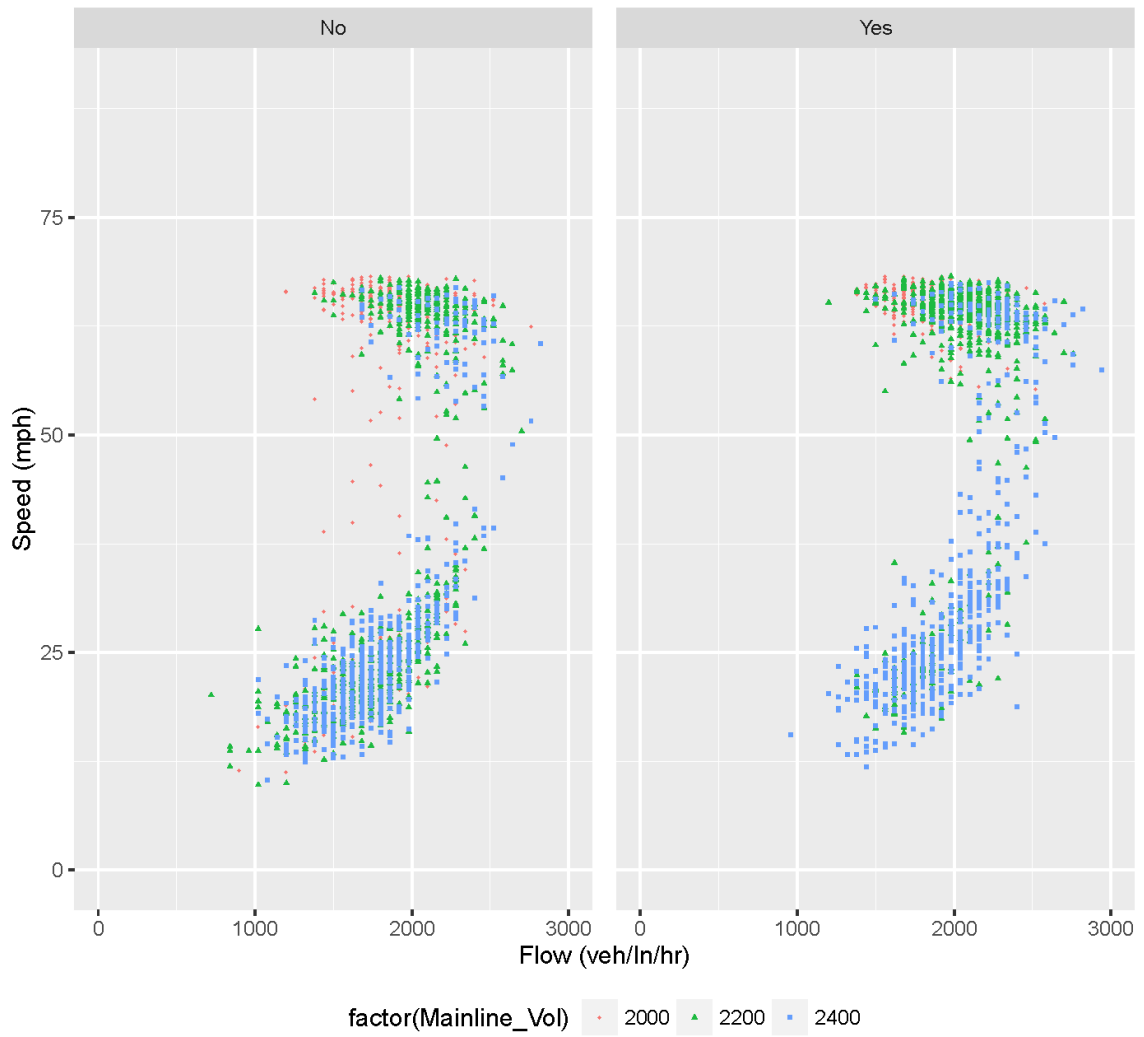


Figure 103: Comparison of Non-Ramp Metered and Ramp Metered Case for All Volumes at the CL.Enter (On-Ramp: 1,000vehs)

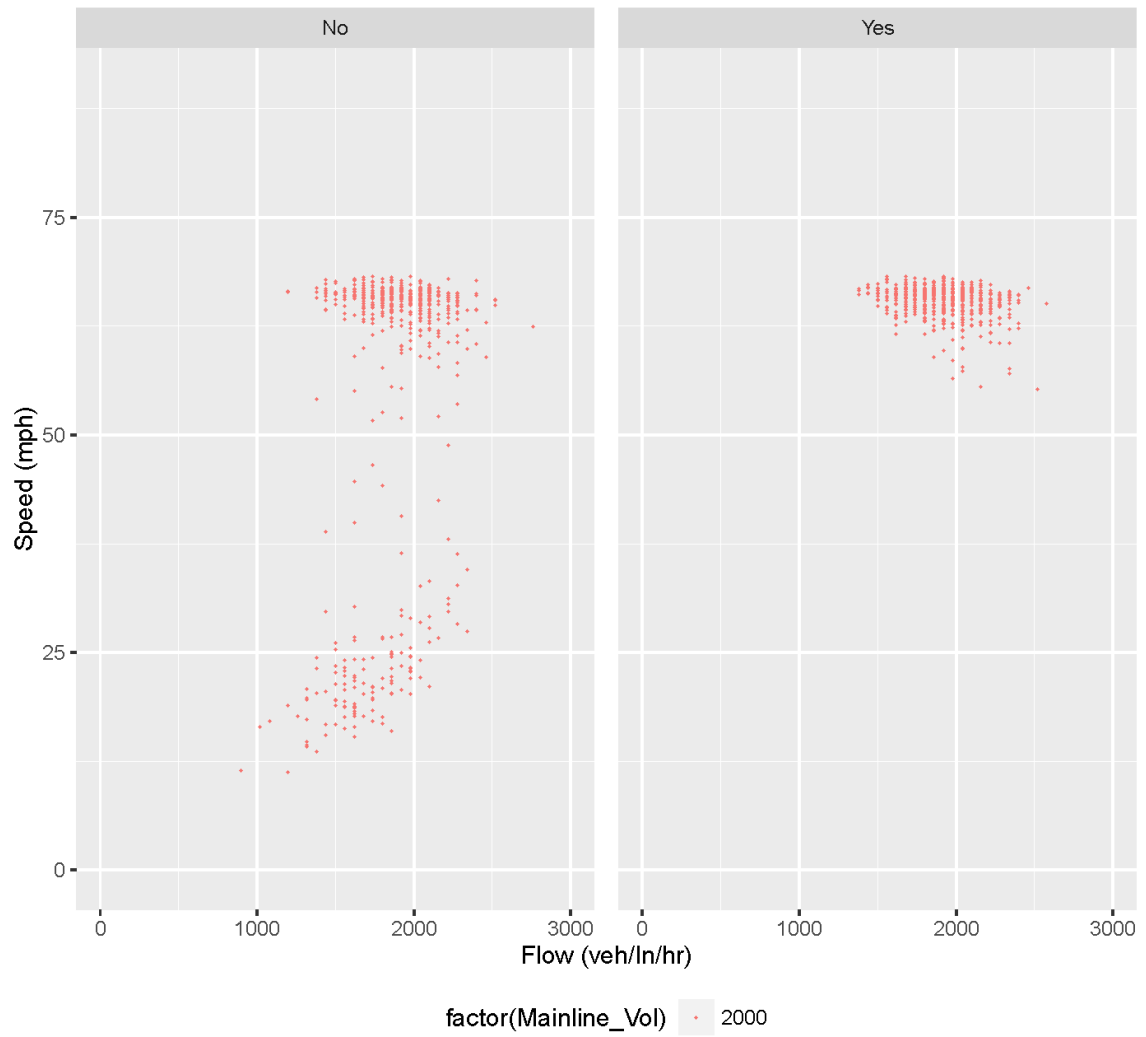


Figure 104: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,000veh/ln at the CL.Enter (On-Ramp: 1,000vehs)

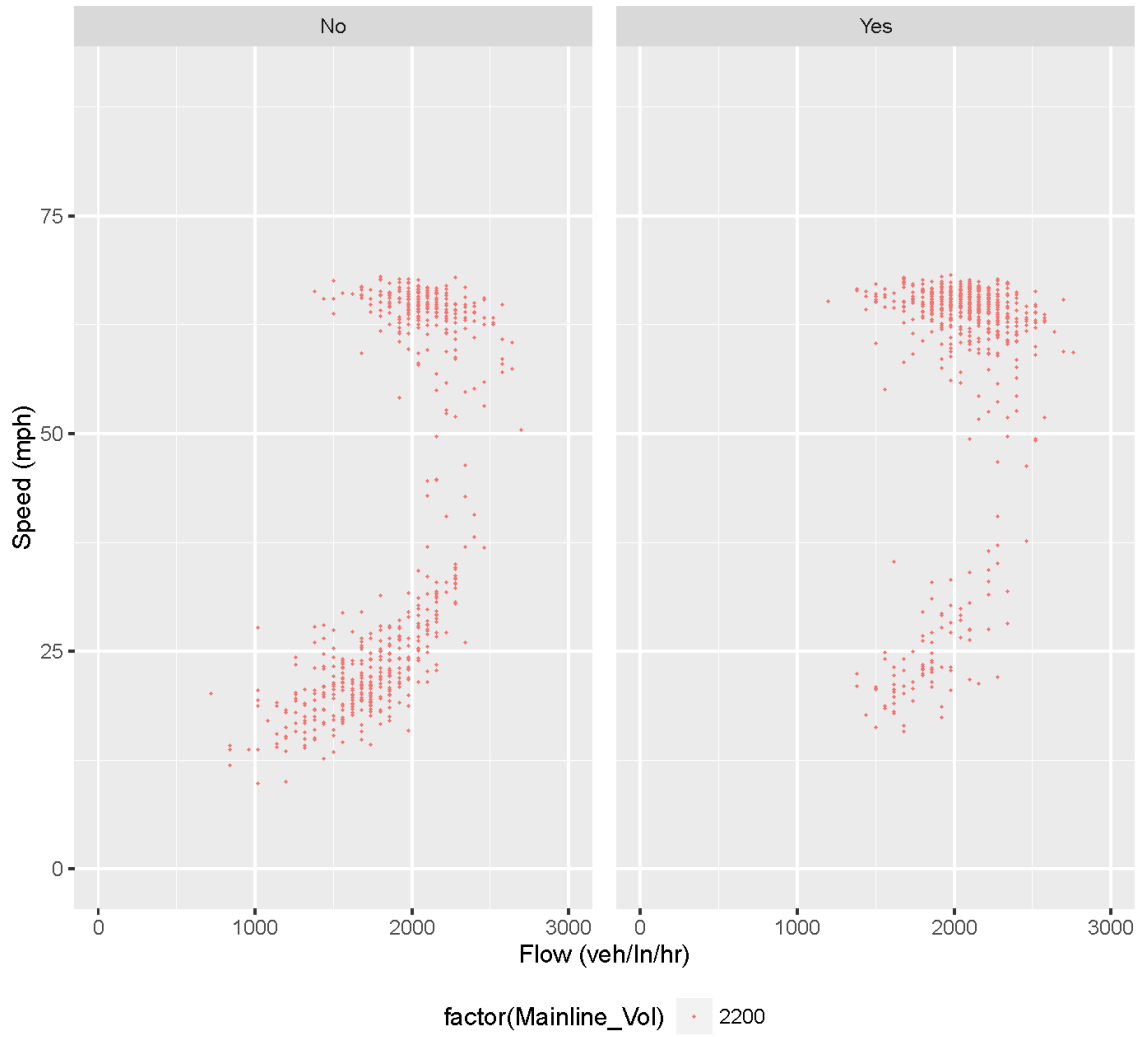


Figure 105: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,200veh/ln at the CL.Enter (On-Ramp: 1,000vehs)

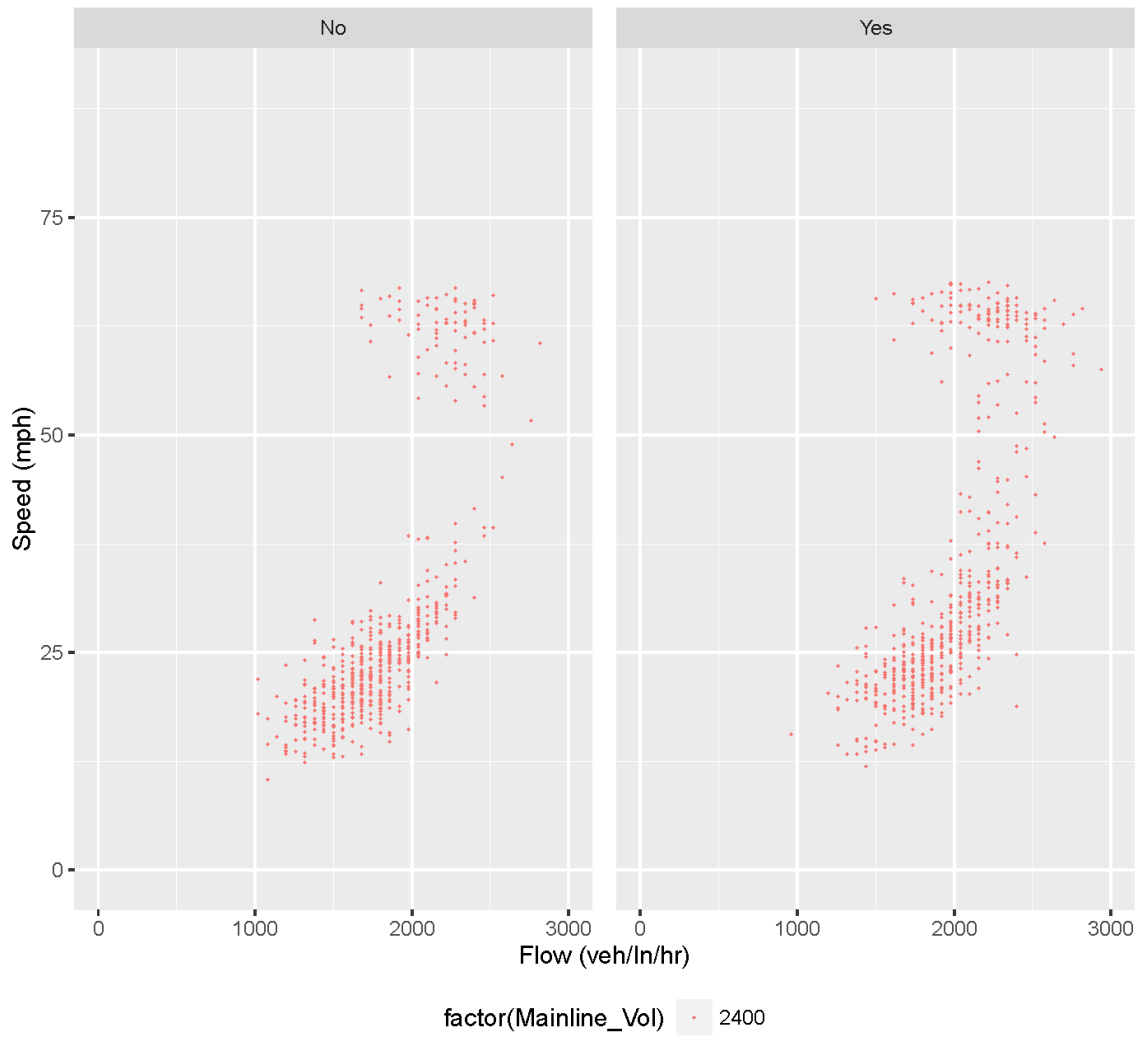


Figure 106: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,400veh/ln at the CL.Enter (On-Ramp: 1,000vehs)

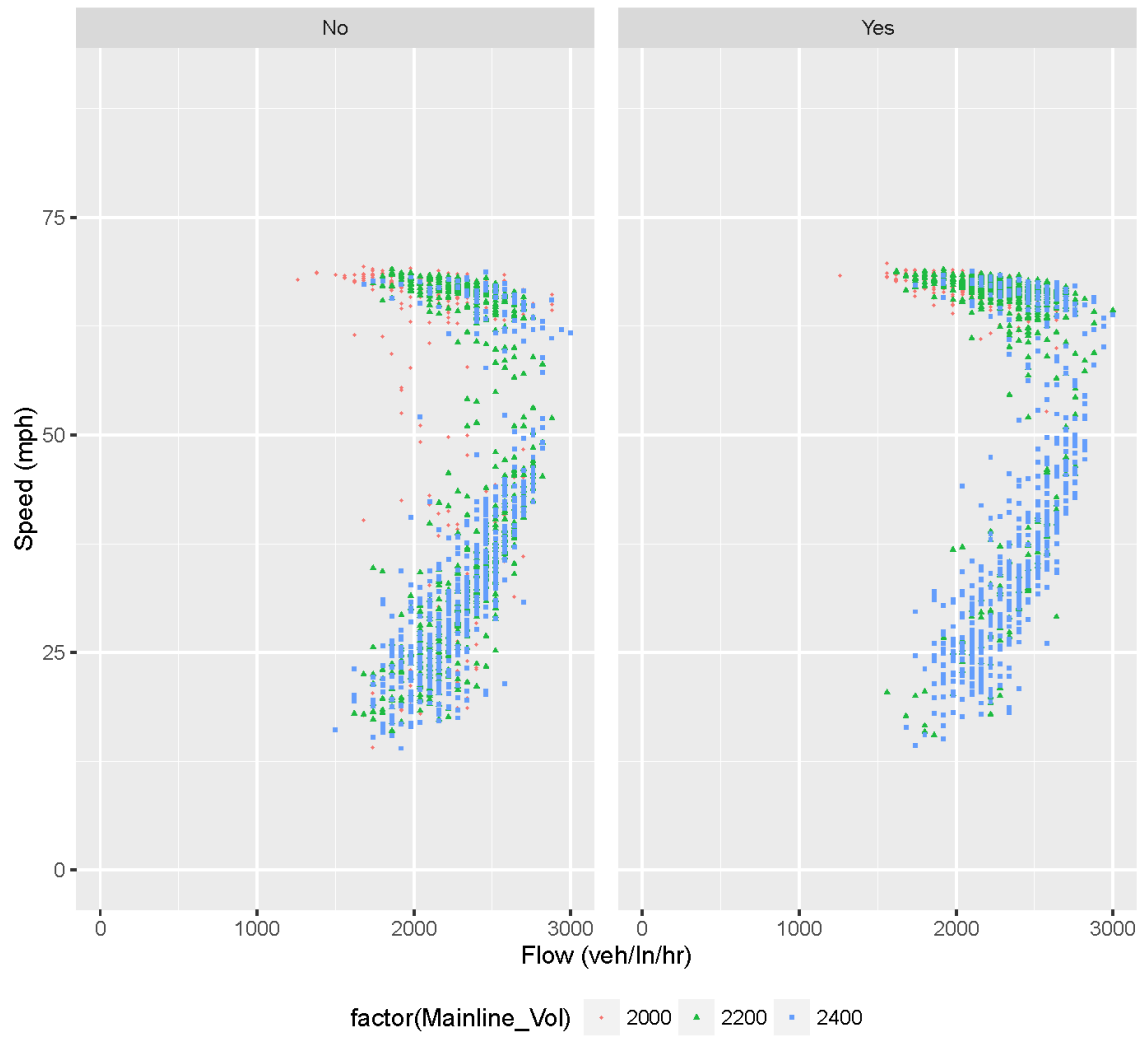


Figure 107: Comparison of Non-Ramp Metered and Ramp Metered Case for All Volumes at the LL.Enter (On-Ramp: 1,000vehs)

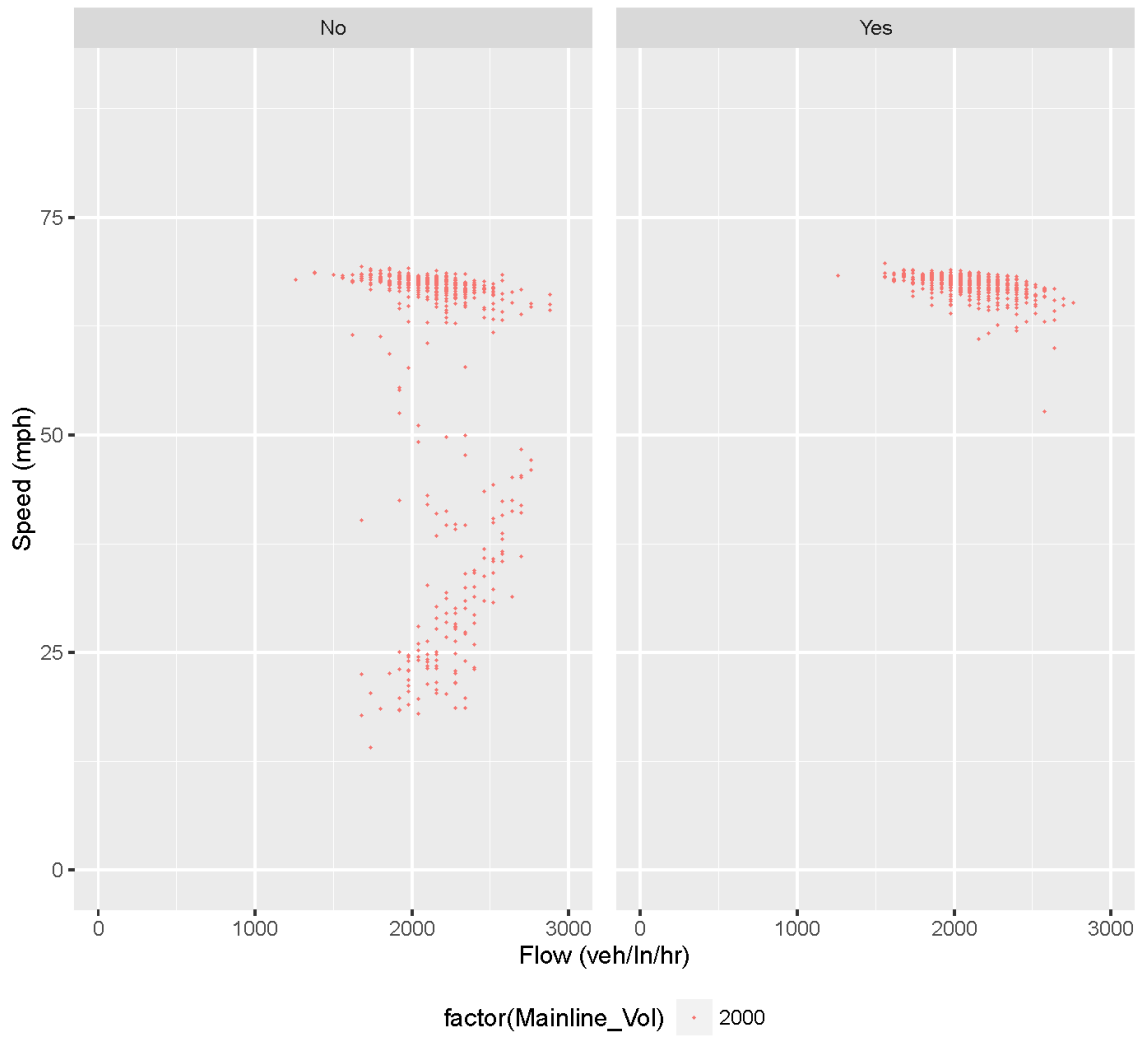


Figure 108: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,000veh/ln at the LL.Enter (On-Ramp: 1,000vehs)

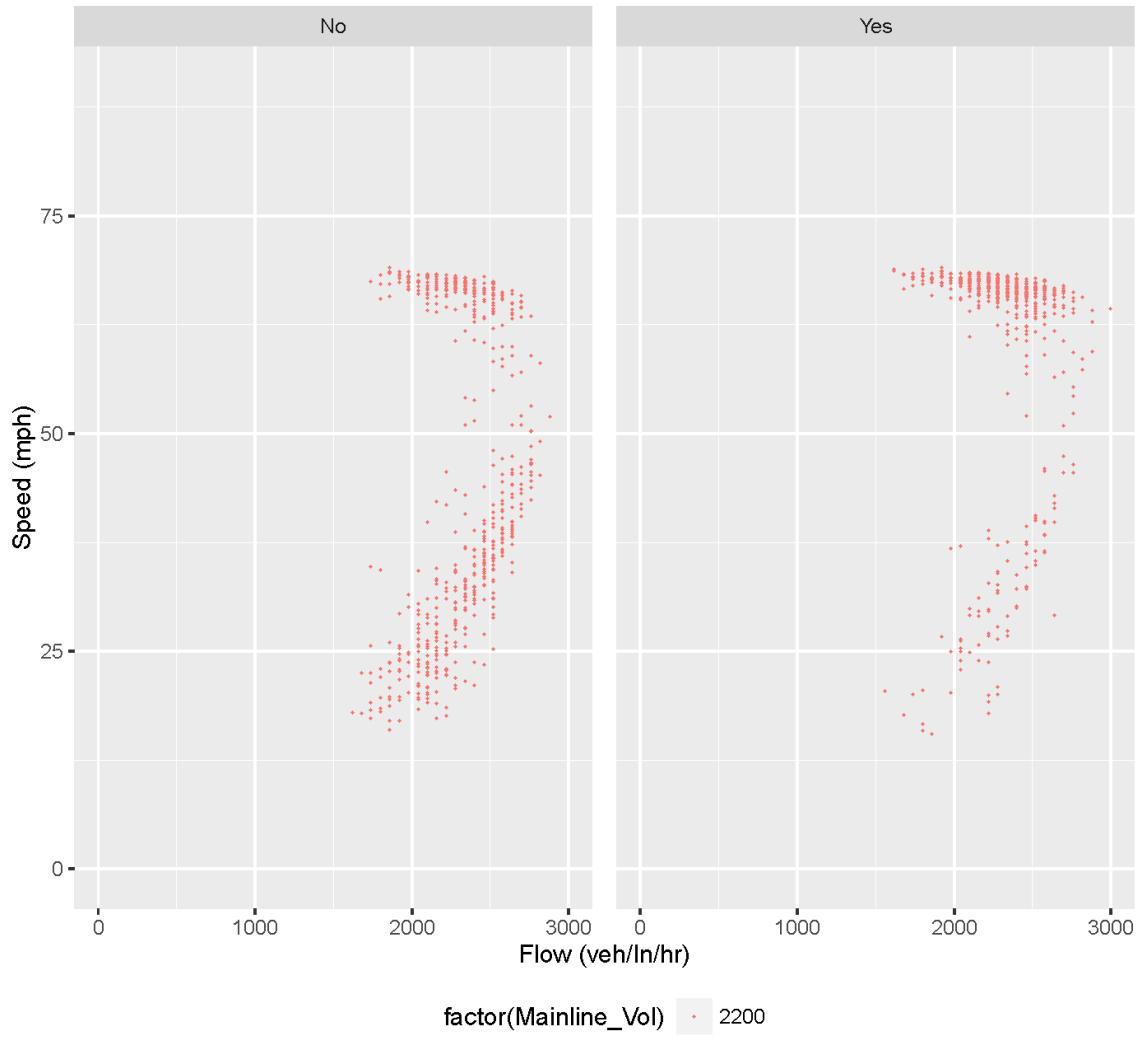


Figure 109: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,200veh/ln at the LL.Enter (On-Ramp: 1,000vehs)

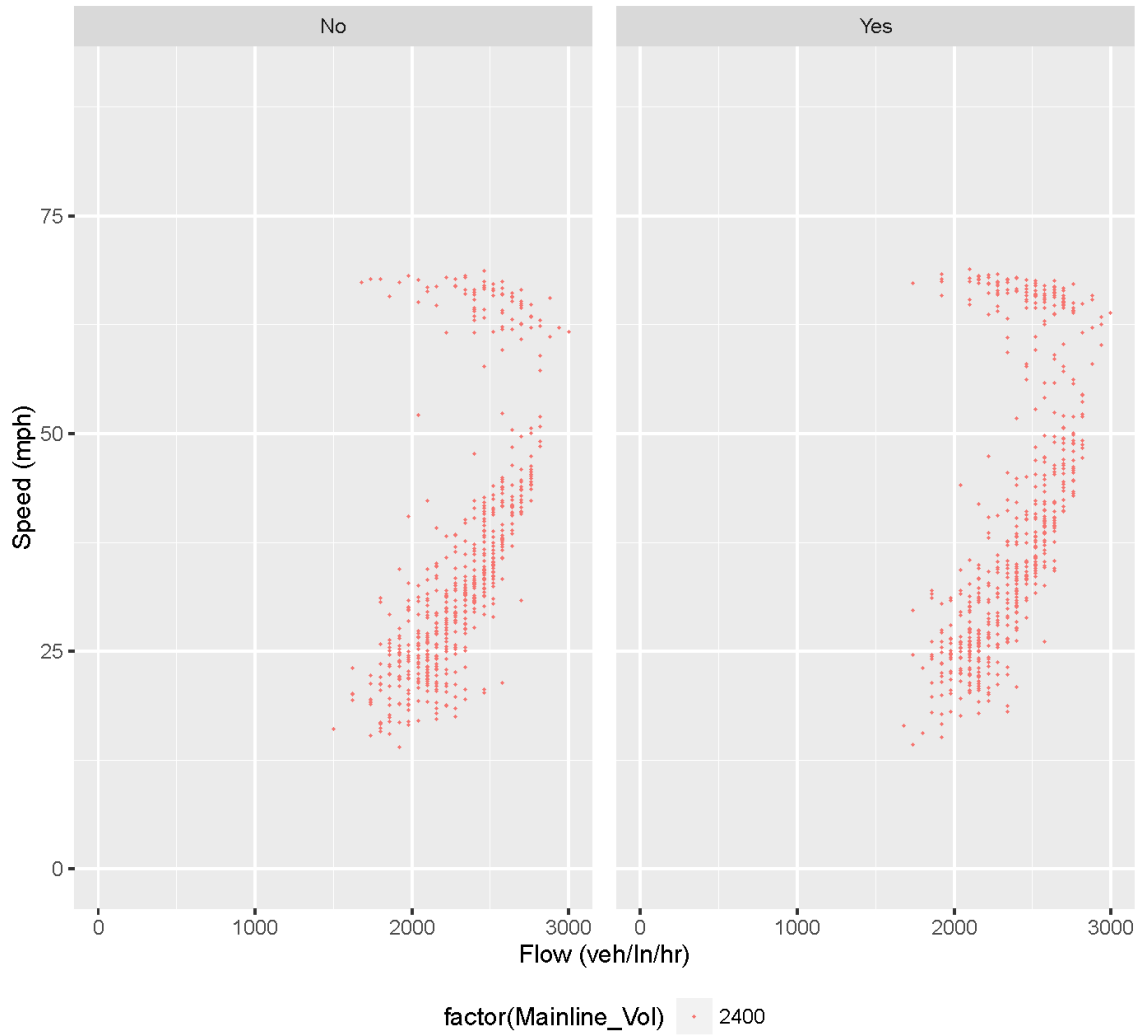


Figure 110: Comparison of Non-Ramp Metered and Ramp Metered Case for 2,400veh/ln at the LL.Enter (On-Ramp: 1,000vehs)

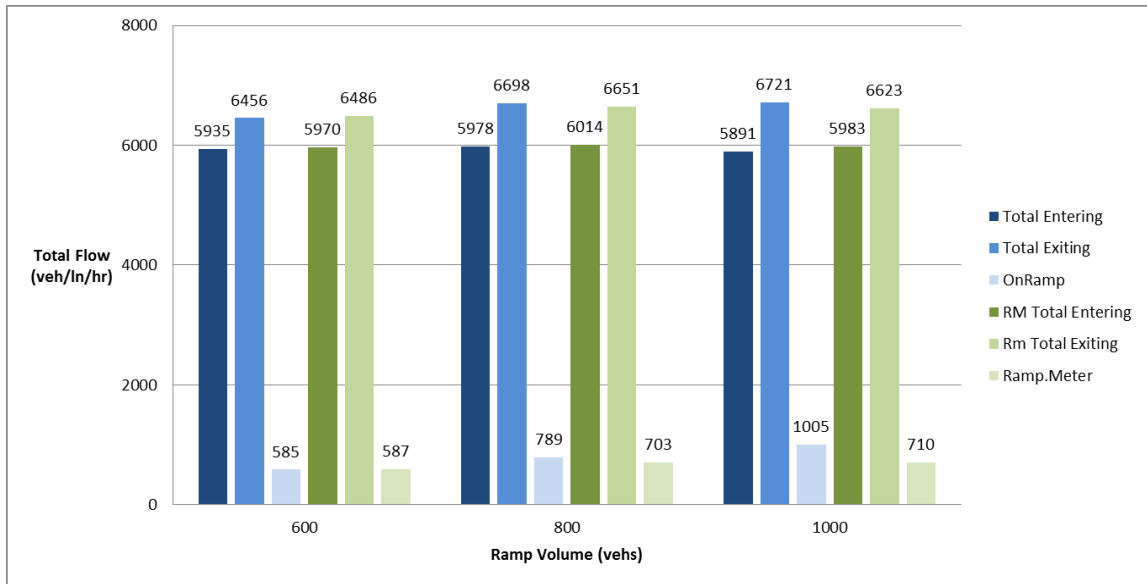


Figure 111: Comparison Bar Plot of Non-Ramp Metered and Ramp Metered Case Total Entering and Exiting Flows for the 2,000veh/ln Mainline Volume

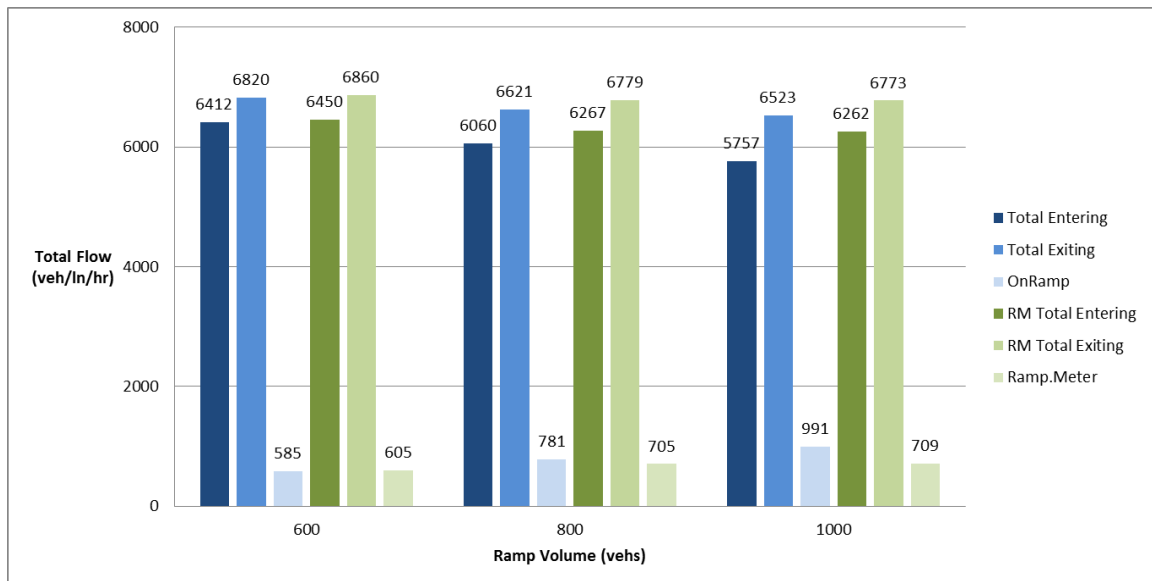


Figure 112: Comparison Bar Plot of Non-Ramp Metered and Ramp Metered Case Total Entering and Exiting Flows for the 2,400veh/ln Mainline Volume

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